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SLIP ALONG THE SAN ANDREAS FAULT ASSOCIATED WITH THE GREAT 1857 EARTHQUAKE

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ABSTRACT

Historical records indicate that several meters of lateral slip along the San Andreas fault accompanied the great 1857 earthquake in central and southern California. These records, together with dendrochronological evidence, suggest that the rupture occurred along 360 to 400+ km of the fault, including several tens of kilometers of the currently creeping reach in central California.

Geomorphic expressions of late Holocene right-lateral offsets are abundant along the 1857 rupture. Along 300 kilometers of the 1857 rupture, between Cholame and Wrightwood, the youngest discernible offset ranges from 3 to $9\frac{1}{2}$ meters. Dormancy of the fault since 1857 almost certainly indicates that this latest offset was created in 1857.

Fault slip apparently associated with the 1857 earthquake varies in a broadly systematic way along the trace of the fault. It is relatively uniform along each of several long segments, but changes rather abruptly in value between these segments. This nonuniform displacement pattern may imply that some segments of the fault rupture more frequently or experience a slower long-term slip rate than others.

The 1857 offsets indicate a seismic moment, m_o, between 5.3 and 8.7 × 10^{27} dyne-cm, assuming a 10- to 15-km depth of rupture and relatively uniform slip as a function of depth. A comparison with the rupture length, average slip value, and tectonic setting of the California earthquake of 1906 ($M_S = 8\frac{1}{4}$) indicates a value of $M = 8\frac{1}{4}$ + for the 1857 event.

Introduction

The California earthquake of January 9, 1857 is one of the great historic earthquakes of the western United States. Contemporary accounts indicate that it was produced by several meters of sudden lateral slip along the south-central reach of the San Andreas fault and was felt over at least 350,000 km^2 (Figure 1). A majority of reports indicate that the duration of the earthquake was between 1 and 3 min.

The dormancy of the south-central reach of the fault since 1857 has prompted suggestions that past and future slip along this reach might well be characterized by great 1857-type events separated by long intervals of dormancy (Allen, 1968). A comparative study of the amount of fault slip associated with the 1857 and earlier events along the south-central reach of the fault would provide a test of the above hypothesis. Such a comparison depends, of course, upon a knowledge of the 1857 fault slip. The acquisition of this knowledge is therefore the major concern of this paper. A forthcoming paper and Sieh (1977, Ch. 2) compare 1857 and earlier slip events.

Wood (1955) has dealt with most of the sparse historical data available for assessing the size of 1857 offsets. A small amount of additional historical information is presented herein. The main body of this paper, however, is devoted to the presentation and geomorphic analysis of the small channel offsets which form the basis for estimating the size and extent of the 1857 offsets.

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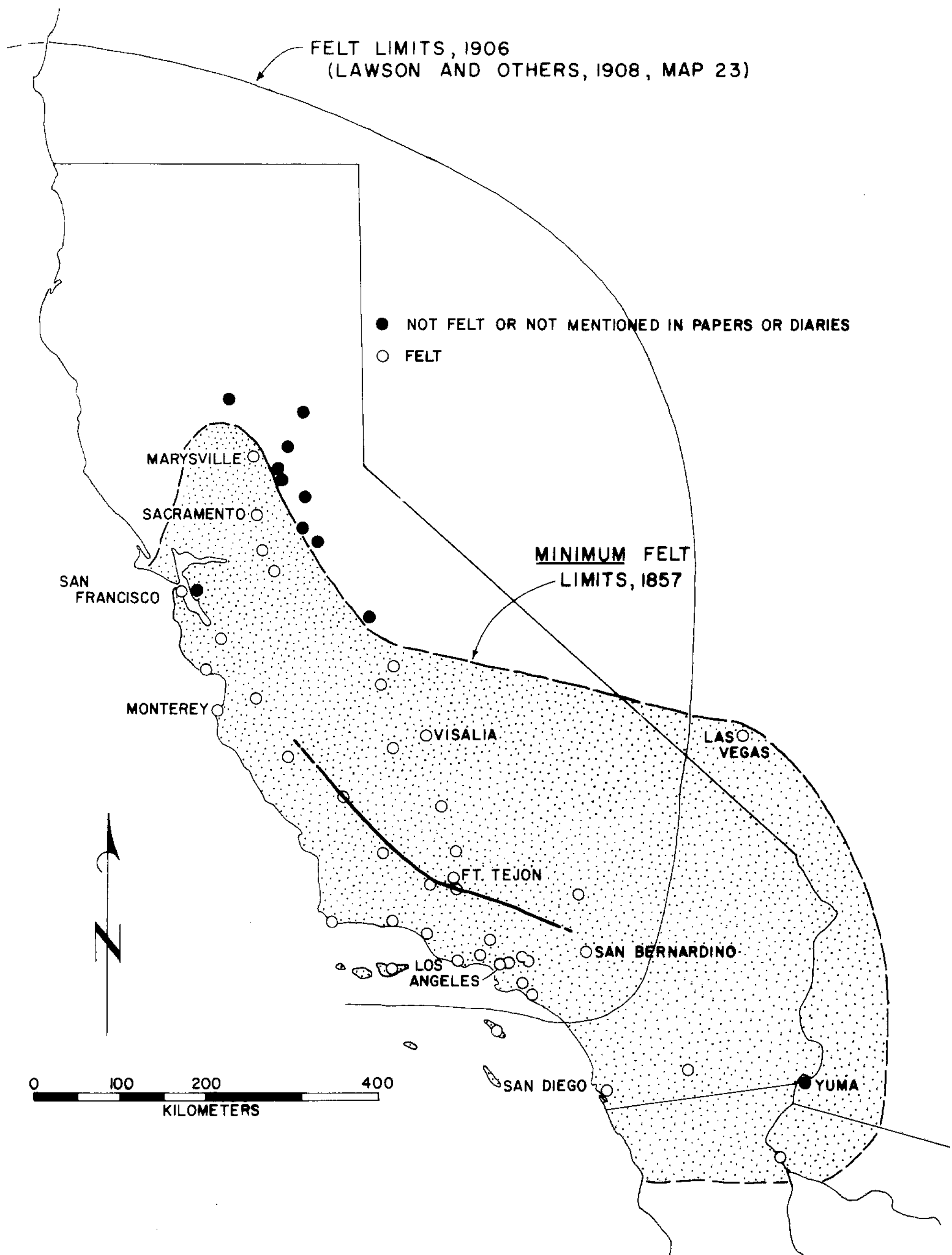

FIG. 1. Felt reports of the great 1857 earthquake (from Agnew and Sieh, in press) and the segment of the San Andreas fault which slipped to produce the earthquake.

BACKGROUND

Extent of surface faulting associated with the 1857 earthquake. Several first- and second-hand contemporary accounts of surface fractures (Wood, 1955) leave little doubt that the great 1857 earthquake was produced by strike slip along at least the 230-km reach of the San Andreas fault from Cholame Valley to Lake Elizabeth (Figure 2). Two later accounts suggest that surface faulting may have occurred as

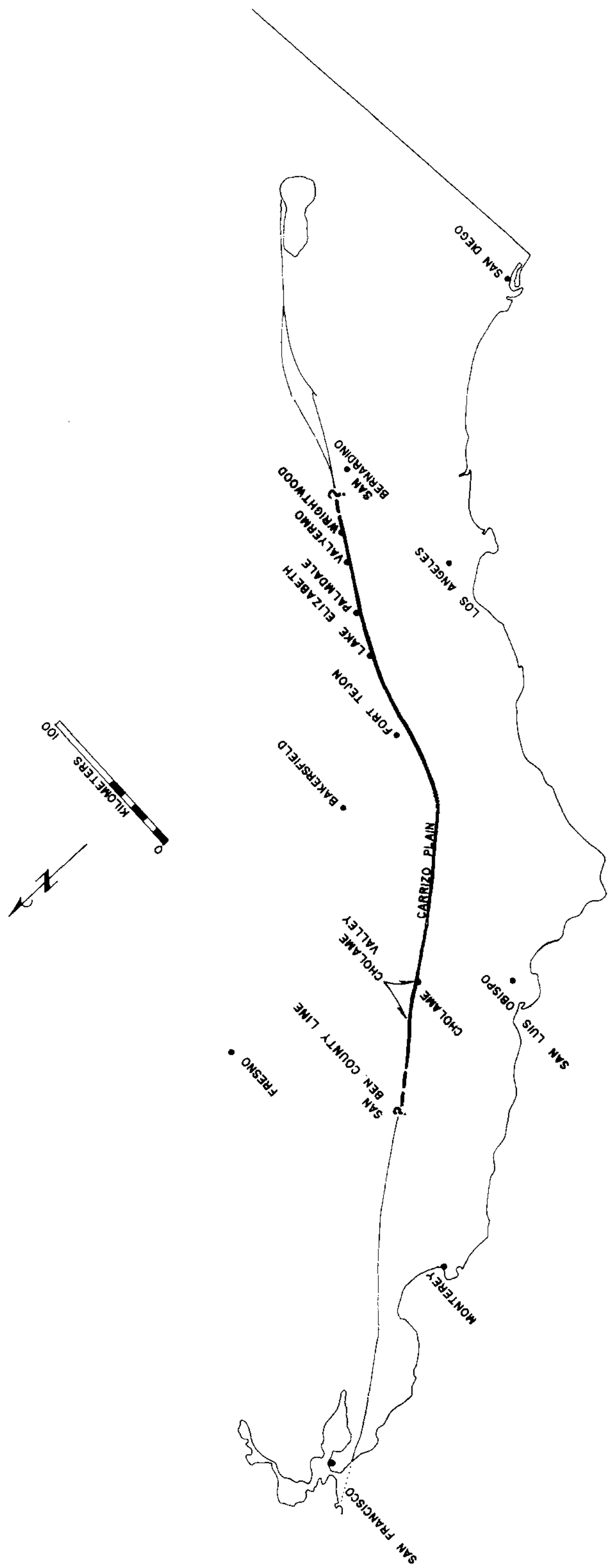

FIG. 2. Extent of fault rupture associated with the 1857 earthquake. The segment of the fault which has been creeping during the period of historical record extends from Cholame to a point northeast of Monterey.

far as 80 km northwest of Cholame (Wood, 1955, p. 47; Johnson, 1905). Johnson (1905, p. 76) remarks that a "Mr. Tracy in '61 traced [the] crack into San Benito Cy. [County]", at least 80 km northwest along the fault from Cholame. Other references to the "earthquake crack" by early settlers near Palmdale and Valyermo (see below) imply that the "crack" refers to fresh surface faulting, and not to the general pre-existing rift topography. Thus the 1857 surface rupture probably extended into San Benito County, at least 80 km into the creeping reach.

There are several reasons to believe that the 1857 rupture extended southeastward beyond Lake Elizabeth. In the first place, eyewitness accounts probably were limited to that reach of the fault between Fort Tejon and Lake Elizabeth which was near and parallel to the well-traveled Los Angeles road. Second, early settlers to the southeast near Palmdale (Schuyler, 1896 to 1897, p. 711–712) and near Valyermo (Noble, 1954) referred to the "earthquake crack" along what is now known to be the fault trace, because, during the latter half of the nineteenth century, fissures and cracks from the 1857 event could still be seen along the fault in these areas. Faulted nineteenth century sediment along the fault near Valyermo is additional evidence for 1857 faulting beyond Lake Elizabeth (Sieh, 1978).

Disturbed trees along the fault trace provide evidence that surface faulting in 1857 may have occurred at least as far to the southeast as Wrightwood. Figure 3 is a topographic map of a site in Wrightwood where three Jeffrey pines are growing directly on a recent "moletrack" along the fault. Figure 4 illustrates the same site.

The upper parts of trees 1 and 2 are relatively untilted. However, tree 1 tilts S22E $\pm$ 3° about 13° in its lower $3\frac{1}{2}$ to 6 m, and tree 2 tilts N52W $\pm$ 5° about 12° in its lower $7\frac{1}{2}$ to 12 m. This may indicate that tree 1 was tilted when it was $3\frac{1}{2}$ to 6 m tall, and that tree 2 was tilted when it was $7\frac{1}{2}$ to 12 m tall. Cores bored through both trees reveal the annual growth rings and enable dating of the trees. Preliminary ring counts indicate that tree 2 was first established in about 1832, and that tree 1 was established in the 1840's. Thus, tree 2 was about 25 years old and tree 1 was about a decade old at the time of the 1857 earthquake. Thus it is conceivable that tree 2, about 25 years old and $7\frac{1}{2}$ to 12 m high, and tree 1, about a decade old and $3\frac{1}{2}$ to 6 m high, were tilted by fault slip and related deformation underfoot in 1857. Supporting this hypothesis is the record of annual rings of tree 2, which indicates an abrupt initiation of asymmetric growth in about 1857. The side of the tree in the direction of tilt suddenly began to add annual rings about twice as thick as their counterparts on the side opposite the direction of tilt. This is a commonly observed reaction of trees to tilting (Page, 1970; LaMarche and Wallace, 1972).

The evidence from these two trees justifies a tentative conclusion that the 1857 fault rupture did indeed propagate southeastward at least as far as Wrightwood.

No conclusive historical evidence for faulting beyond Wrightwood in 1857 is known. Intensities at San Bernardino, in fact, were mild enough (Modified Mercalli VI) to suggest that rupture did not propagate as far to the southeast as San Bernardino (Agnew and Sieh, 1978).

Amount of displacement. Published descriptions of the moletrack-like disturbances along the fault trace near Fort Tejon suggest that fault slip in 1857 was dominantly strike slip (Wood, 1955). Barton's description (in Wood, 1955, p. 47) clearly indicates strike slip

> "The fracture presented an appearance as if the earth had been bisected, and the parts had slipped upon each other. Sometimes the earth on one side would be several feet the highest [sic], presenting a perpendicular wall of earth or rocks. In some places the sliding movement seems to have been horizontal, one

side of the fracture indicating a movement to the northwest, the other to the southeast. The fracture pursued its course over hill and hollow, and sometimes this sliding movement would give to the points of the hills and to the gulch channels a disjointed appearance."

Two eyewitness accounts, acquired by geologist Harry R. Johnson in the early 1900's, suggest the general size of the 1857 fault slip. In 1905 an old cowboy, who claimed to have experienced the earthquake while herding cattle near the fault in the southern Carrizo Plain, explained to Johnson that he had observed a small round sheep corral which had been converted into a "rude S-shape" by slip on the fault (Wood, 1955, p. 63). This probably indicates right-lateral slip of at least several meters along the fault at that locality. The remains of this corral have never been

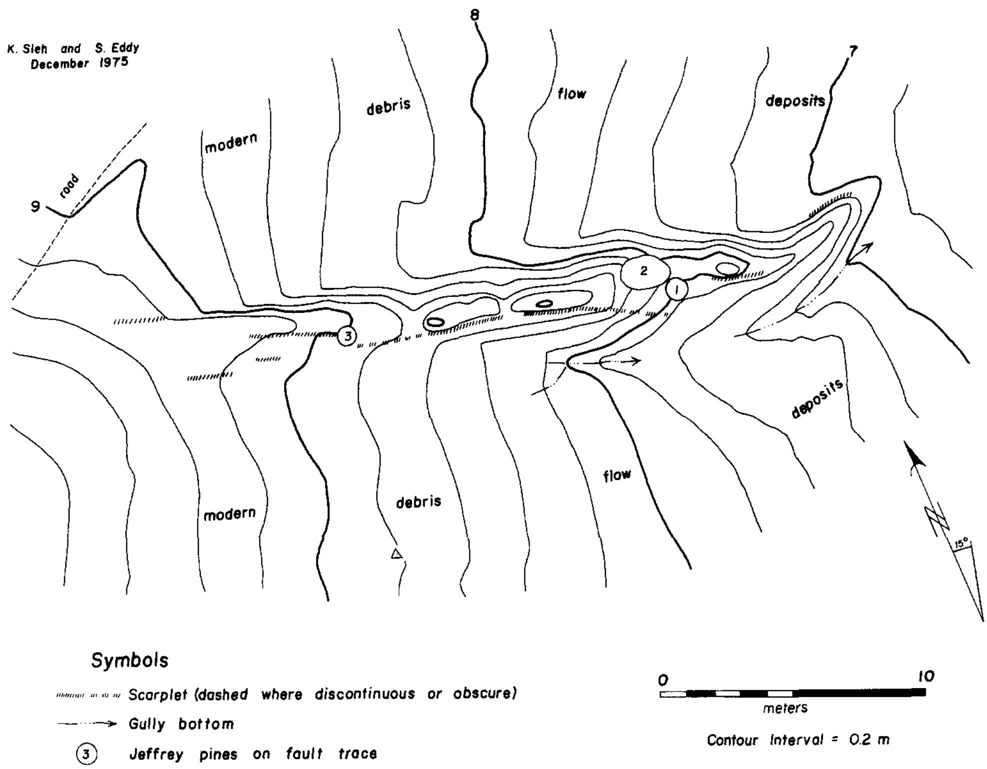

FIG. 3. Topographic map of a welt or "moletrack" produced by recent fault movement at Heath Canyon in Wrightwood, California. Two of the trees growing on the "moletrack" were probably tilted by fault slip and related deformation underfoot in 1857.

located, hence a precise measurement has not been possible. Johnson's 1905 field notebook (Sieh, 1977, Appendix I) has a crude sketch of a large rectangular corral, the configuration of which indicates it experienced right-lateral offset of several meters prior to 1905. Most of this offset is probably the result of slip in 1857. The location of this second corral is uncertain, but the context of the notes suggests that it was near the head of Cholame Creek, some 40 km northwest of Cholame.

Later investigators (e.g., Wallace, 1968) report that, in the Carrizo Plain, small stream channels are typically offset 20 to 35 feet (6 to 11 m). This also lends credence to the notion that the 1857 event was accompanied by several meters of strike slip.

Historical seismicity. Most of the reach of the San Andreas fault along which rupture occurred in 1857 has been seismically quiet during the past 45 years of instrumental recording. Between Cholame and Wrightwood the only substantial post-1857 event that might be correlated with slip on the San Andreas fault was the $M \approx 6$ Tejon Pass earthquake of 1916 (Hileman *et al.,* 1973). But no appreciable surface rupture was associated with that event (Branner, 1917). Surveys of the fault reveal that microearthquakes occur relatively infrequently ($\ll$1 event/day/24 km radius) between Cholame and Valyermo, except at Tejon Pass where an average of 2 events/day was recorded (Brune and Allen, 1967, Figure 3). Recent surveys (H. Kanamori, personal communication, 1977) show similarly low levels of microearthquake activity along the 1857 reach of the fault, except near Palmdale where the level of activity has been mysteriously higher during the past two years (McNally *et al.,* in preparation).

FIG. 4. Photograph of the trees growing on the "moletrack" illustrated in Figure 3. Annual growth rings of the two trees on the right indicate they were probably tilted by fault slip in 1857. The tree on the left is only about 65 years old and is not tilted.

Northwest of Cholame and southeast of Valyermo and Wrightwood, levels of historical seismicity are high. Microearthquake activity is at a level of 1 to several events/day/24 km radius (Brune and Allen, 1967, Figure 3), and felt events occur occasionally. At least four moderate earthquake sequences associated with fault slip of a few tens of centimeters or so have occurred historically near and northwest of Cholame (1901, 1922, 1934, and 1966). This is reflected in the appearance of the youngest features along the fault trace. In contrast with the entire reach from Cholame to San Bernardino, where the "microtopography" has been all but masked by sediment, very small hummocks and swales and subdued fissures are still very obvious along much of the 1966 rupture.

Several moderate earthquakes have occurred on or near the San Andreas fault southeast of Wrightwood: 1899 ($M \approx 6+$, Cajon Pass), 1907 ($M \approx 6$, San Bernardino), 1923 ($M \approx 6\frac{1}{4}$, San Bernardino), and 1970 ($M_L = 5.4$, Lytle Creek). Surface faulting is not reported to have been associated with these events; however, it seems that only the 1923 event was followed by a systematic search for fault slip in the epicentral area (Laughlin *et al.,* 1923). No unequivocal fault creep has been observed in the region of these events.

Historical creep. No fault creep has been observed along the San Andreas fault between a point a few kilometers southeast of Cholame and the Salton Sea. None of the fences between Cholame and the Carrizo Plain are offset along the fault (Brown and Wallace, 1968). Some of these fences were built in the first decade of the twentieth century. Pipelines established in the early twentieth century across the fault at Tejon Pass and Elizabeth Lake show no signs of deformation (C. R. Allen, personal communication). West of Tejon Pass a large pine tree growing directly on the freshest fault trace has not been appreciably disturbed by fault slip. Preliminary counts of annual rings indicate that this tree sprouted on the fault trace between 1858 and 1862. Once its root system was well established in the soil on both sides of the fault, the tree would not have been able to accommodate much more than a few tens of centimeters of fault slip without splitting and/or tilting. This is observed in the creeping zone northwest of Cholame where small trees are clearly being split by creep (N. T. Hall, personal communication, 1975). Therefore, it seems reasonable to conclude that west of Tejon Pass appreciable fault afterslip did not occur after the late 1860's.

A Jeffrey pine in Wrightwood (tree 3, Figures 3 and 4) has been growing on the freshest fault scarp since about 1915. This suggests little, if any, fault slip there in the twentieth century.

Basis for this study. The dormancy of the fault since 1857 implies that at any one locality between Cholame and Wrightwood, where many small reference features such as stream channels, landslides, and alluvial fans are offset, the smallest offsets probably are the result of the 1857 event (afterslip in the following few months or years is considered to be part of the 1857 event). This presumes that the creation of the youngest features that are offset preceded the 1857 event but postdated the youngest prior slip event. This is a reasonable assumption because of the frequency with which channel segments, fans, and other reference features are newly formed, and the apparent lack of historic fault activity prior to 1857. Although the seismic history of the San Andreas fault for the several decades prior to 1857 is poorly known, it is highly improbable that any large seismic events and associated slip occurred along this reach of the fault during at least the 88 years of historical record preceding 1857. This almost certainly was ample time for development of fresh reference features across the fault prior to the 1857 event. Dozens of features display no offset today along the south-central reach of the fault. Old aerial photographs (Fairchild Aerial Surveys, Job #3883, scale 1″ = 2000′) provide documentation that many of these post-1857 features in the Carrizo Plain formed before 1929; that is, within the 70 years following the 1857 event. Within the past 6 years alone, flash floods and debris flows there have provided opportunity for the creation or utilization of at least three new sets of reference features (Winter 1972–1973, Sept.-Oct. 1976, and Winter 1977–1978).

Methods. By careful examination of aerial photographs I first located most of the youngest offsets between Cholame and San Bernardino (U.S.G.S. WRD, 1966 1:6000-scale series and I. K. Curtis, 1971 1:12,000-scale low-sun-angle series). Some of the most subtle offsets were first recognized during field investigation, however. I have traversed most of the 350-km study reach at least once in the course of field investigation. Each of more than 150 measurements of offsets that I have reported (Table 1) is based on at least $\frac{1}{4}$ hour of field examination including detailed sketching and careful measurement of offset amounts by tape. Nineteen of the offsets have also been mapped by plane-table methods, in order to document more objectively their expressions and amounts. Comparisons of sketch and plane-table maps reveal elements of subjectivity and inaccuracy in the sketch method, but confirm the general reliability of the measurements made by tape.

Reported offsets (Table 1) have been assigned designations of Excellent, Good, Fair, and Poor according to their estimated reliability as indicators of tectonic fault slip. Thus Excellent (Exc.) and Good (G) designations generally reflect the absence of complicating secondary faults, little or no indication of lateral warping, sharpness of offset expression, and localities with relatively simple or clearly interpretable geological and geomorphic features. In several places, where very reliable (Exc and G) data do not exist, less reliable (F and P) sites were utilized.

Errors in determining actual fault slip were minimized by excluding from the data set measurements at sites where nontectonic processes are likely to have influenced the apparent offset of a feature. Sites where such influences cannot be reasonably excluded as a possibility were also avoided. The principal categories of unreliable sites are (1) stream channels deflected around uphill-facing scarps, (2) irregular channels displaced across several-meter-wide fault zones, and (3) possibly offset features at localities where the fault trace cannot be precisely located.

1857 Displacements

There is a marked coincidence of smallest offset values in many areas along the south-central reach of the San Andreas fault (Figure 5). Southeastward for about 20 km from Highway 46 near Cholame, the smallest offsets are mainly in the range of 3 to 4 m. Along the fault in the northern half of the Carrizo Plain, the smallest offsets are principally between 8 and $9\frac{1}{2}$ m. From the southern Carrizo Plain to at least 10 km southeast of Tejon Pass, the majority of the latest offsets cluster between 5 and 7 m. Offsets between Elizabeth Lake and Wrightwood are tightly clustered between about 3 and $4\frac{1}{2}$ m.

Several of the best sites for studying offsets are described and illustrated below. Figures 6, 7, and 8 are photographs of examples of the types of reference features studied. These include offset gullies, alluvial fans, and landslide scarps.

Sites 82, 83, and 84. Near the southern end of the Carrizo Plain, about 3 km northwest of Highway 166, the Soda Lake Road cuts into the scarp of the San Andreas fault. Just to the southeast of this cut, on the flat between the scarp and the road, are six very small alluvial fans (Figures 6 and 9). Three of the six are younger fans that receive the discharge from three short gullies cut into the scarp face. Water has run in these gullies probably only once or twice since they were mapped in the summer of 1975. The most recent known discharge occurred during a very heavy rain just a few days before October 3, 1976. Debris was deposited as grassy, pebbly levees on the rims of small, narrow lobes within a few meters of the apex of each young fan. Only 1000 to 2000 cm^3 of new material was added to each fan during this event. This amounts to about 0.0002 to 0.001 of the fan volumes and indicates that the fans have been building gradually over many years or decades.

Three older fans are offset about $6\frac{1}{2}$ m in a right-lateral sense from the three gullies. Enough time has passed since the offset of these gullies occurred to allow aprons of slope-wash deposits to completely bury any microtopographic features developed along the fault during the displacement event(s). The well-defined apices of some of the fans, both young and old, and fan symmetry suggest that all $6\frac{1}{2}$ m of

TABLE 1

OFFSET MEASUREMENTS ALONG THE FAULT

Site	Distance SE from Hwy 46	Rating	Offset	Description	Location
0	-1.4 km	Exc	1.68±.15 m	NW-most of 2 offset gullies. Probably all post-1857.	
		Exc	1.05±.15	SE-most of 2 offset gullies. Slide on NW side has reduced apparent offset by ≤30 cm.	
1	1.3	G	3.5±0.2	Offset gully. See plane-table map.	Just SW of road subparallel to fault about 1.3 km SE of Hwy 46. Just inside landgrant, adjacent to sec. 29, T25S, R16E.
2	1.8	Exc/G	7.2±0.3	Very short gully.	SW of road subparallel to fault about 1.8 km SE of Hwy 46. About on boundary of landgrant and sec. 29, T25S, R16E.
3	2.5	P	4.2±0.2	Gully has been cut through high ridge downstream from fault. May never have been alignment of upstream and downstream segments.	At boundary of landgrant and NW¼ of NE¼ sec. 32, T25S, R16E.
4	4.3	F/P	9.1±0.6	Possible warp upstream and downstream from fault. Gully.	SE¼ SW¼ sec. 33, T25S, R16E, near boundary of T26S.
5	12.5	F/G P	2.7±0.6 3.8±0.8	Two gullies offset at head of large gully. SW gully freshest and sharpest offset--perhaps up to 11.3±0.8 m total offset. NW gully total offset about 10 m. Poor fault location results in uncertainty.	SW¼ SE¼ sec. 24, T26S, R16E, just inside E boundary. About 230 m NW of sec. 24/sec. 25 boundary and fault-trace intersection. Bitterwater Valley.
6	12.7	P F	3.8±0.6 3.8±1.0	3.8±0.6 on stream channel--not valid if slide moved in or after 1857. 3.8±1.0 on steep SE flank of creek. Latest offset of large channel and slide. (Unpublished plane-table map.)	SW¼ SE¼ SE¼ sec. 24, T26S, R16E, about 80 m NW along fault from sec. 24/sec. 25 boundary. Bitterwater Valley.
7	12.8	G	$\sim$2 m	Minimum value. Free face on SE side of gully.	NW¼ of NE¼ of NE¼ sec. 25, T26S, R16E about 70 m SE along fault from sec. 24/sec. 25 boundary. Bitterwater Valley.
8	13.0	F/G	6.7±2.1	Gully. Imprecision due to uncertainties at NW end.	NW¼ sec. 25, T26S, R16E, just NW of large landslide in serpentine.
9	14.1	Exc/G	7.0±0.6	Large channel in canyon offset along freshest-appearing trace.	About 110 m SE of "Carter grade" asphalt road. Sec. 30, T26S, R17E.
10	16.3	G	2.8±0.3	Offset stream channel along main trace. Offset along two other geomorphically young traces not included. This, therefore, is a minimum figure, but probably close to offset value if other traces were to be included.	About 90 m NW of dirt road. NE¼ of SE¼ of sec. 31, T26S, R17E. Bitterwater Valley.
11	18.0	Exc	4.1±0.9	Gully. See plane-table map and discussion in text.	About 570 m NW of Jim Grant farm building driveway. SE¼ NE¼ sec. 5, T27S, R17E.
12	18.7	Exc	$3.2^{+0.2}_{-0.5}$	Gully.	Across road from Jim Grant farm buildings. SW¼ SW¼ sec. 4, T27S, R17E.
13	18.7	Exc	3.4±1	NW edge of landslide. Scarplet also visible in slide deposits.	Next drainage SE from above site.
14	19.0	P/F	6.1±0.6	Offset gully originates in a small landslide. Expansive soil. Upstream and downstream segments are not parallel.	About 400 m SE from Jim Grant farm building driveway. SE¼ SW¼ sec. 4, T27S, R17E.
15	21.5	Exc	3.3±0.6	Offset gully on alluvial fan depositing against ridge. Small, broad, about 1.2 m deep. Bottom well-defined and straight, except at fault.	About 100 m SE of Bob Grant driveway NW¼ NE¼ NW¼ sec. 15, T27S, R17E. Bitterwater Valley.
16	34.0	F/P	5.5±2.1	Deeply incised gully in alluvial deposits. Fault trace geometry and position uncertain. This may be a deflection.	NE¼ NW¼ SE¼ NW¼ sec. 16, T28S, R18E.
17	34.8	F/P	5.5±0.9 11.0±1.2	Offset headscarp of landslide. Fault traces complex here. Appear to make left step of several hundred meters. There may well be additional slip on faults to NE.	SW¼ SW¼ SW¼ NE¼ sec. 16, T28S, R18E.
18	54.5	Exc	8.0±0.5 20.5±0.7	Beheaded gullies. See plane-table map.	SE¼ SE¼ SW¼ sec. 35, T29S, R19E. About 2.55 km NW of Hwy 58 along fault.
19	56.6	G	9.4±1.2	Large gully intersects fault at low angle.	NW¼ sec. 12, T30S, R19E. About 300 m NW of Hwy 58 along fault.
20	62.5	Exc	48.2±2.4	Offset gully.	NW¼ SW¼ SE¼ sec. 20. About 30 m SW of dirt road.
21	65.8	Exc	8.5±1.2	Alluvial fan offset from gully.	NE¼ sec. 33, T30S, R20E. Between abandoned channel (offset 350 m) and new channel (offset 126 m) of Wallace Creek. Northern Carrizo Plain.
23	66.3	Exc	9.4±0.9	Offset gully.	NW¼ SW¼ sec. 34, T30S, R20E. One of a set of offset gullies SE of Wallace Creek.
24	66.3	Exc	9.1±1.8 19.0±1.5 37.2±2.4 47.2±2.4 64.0±2.7	As above.	As above.
25	66.4	G/Exc	8.7±1.4 24.1±1.4 32.0±2.0 56.4±2.9	As above.	As above.
26	66.4	G	9.2±0.9 22.6±1.5 33.5±1.5	As above.	
27	66.5	Exc	9.8±1.2	As above.	
28	66.7	G	9.4±0.6	Shallow gully in alluvial deposits.	About 580 m SE of Wallace Creek.
29	67.8	Exc	19.6±1.8	Sharp offset of channel deeply incised in alluvium (Wallace, 1968, Figure 9). Offset calculated by averaging offset of top of bank on NW side of channel (17.8±1 m) and channel bottom (21.4±1 m).	NE¼ SW¼ NE¼ sec. 3, T31S, R20E. Northern Carrizo Plain.

TABLE 1

OFFSET MEASUREMENTS ALONG THE FAULT

Site	Distance SE from Hwy 46	Rating	Offset	Description	Location
30	68.8	Exc	8.35±.25	Small gully on high scarp offset from small (15 cm high) fan. Many other offsets are apparent along this scarp to SE, but geologic uncertainties preclude their use in this table.	SE¼ NE¼ SE¼ sec. 3, T31S, R20E. Northern Carrizo Plain.
31	70.7	Exc	9.1±1.0	Shallow gully on active alluvial fan. See plane-table map and discussion	SE¼ sec. 11, T31S, R20E. E of dirt road about 80 m.
32	71.5	Exc	18.3±0.9	Sharp offset of channel deeply cut into alluvium. Value includes "warp" within about 3 m of en echelon fracture zone.	SE¼ SW¼ SW¼ sec. 12, T31S, R20E. About 30 m NW of sec. 12/sec. 13 boundary.
33	71.9	G	9.6±1.4	Offset deeply-incised channel. Value is an average of unwarped (8.7 m) and warped (10.5 m) possibilities.	NE¼ NW¼ sec. 13 T31S, R20E. About 370 m, SE of sec. 12/sec. 13 boundary.
34	73.9	Exc	6.3±0.8	NWern offset channel and SEern offset channel on main fault.	Center of NW¼ NW¼ sec. 19, T31S, R21E. About 240 m SE of corner secs. 13, 18, 19, and 24.
35	73.9	Exc	4.5±0.9		
36	76.6	F	6.5-10.9	Deeply-incised short channels. Second trace to SW may also exist.	NW end of long graben. NW¼ sec. 29, T31S, R21E. About 600 m SE of sec. 29/sec. 30 boundary.
37	76.6	F	9.0±1.0		
38	80.7	G	14.6±0.8	Wide sandy-bottomed channel.	About on sec. 3/sec. 4 boundary T32S, R21E.
39-43				Data lost.	W½ sec. 3, T32S, R21E.
44	83.6	F	27.7±2.7	Downstream segment of this offset may have originated across the fault from the next large stream channel to SE.	See photo and discussion in text. W½ sec. 11, T32S, R21E. Van Matre Ranch, Carrizo Plain.
45	83.6	G	15.2±0.9	Deeply-incised channel offset.	As above.
46	83.7	Exc	$8.2^{+0.6}_{-1.5}$	Short scarp-face gullies with three beheaded gullies.	As above.
		F/P	16.2±0.9		
		Exc	25.1±0.9		
47	83.7	Exc	$8.2^{+1.5}_{-0.3}$	Beheaded gully.	As above (and see plane-table map).
		Exc	24.4±1.0		
48	83.8	Exc	7.8±0.6	Beheaded gully.	As above.
		Exc	15.8±1.2		
49	83.8	G	8.5±1.5	Short gully and broad beheaded channel.	As above (Not on plane-table map.)
50	83.8	Exc	7.6±1.5	Gully and beheaded channels. A lower value (say 25 m) may be preferred, if colluviation covered part of the old channel.	As above.
		G/Exc	27.9±1.8		
51	85.2	P/F	13.9±0.8	Much post-1857 headward erosion of beheaded gully ("spring-sapping"?). No fault trace clearly evident. Incision of source gully in post-1929 photos.	NE¼ NE¼ NE¼ sec. 14, T32S, R21E. About 100 m NW of sec. 13/sec. 14 boundary. Carrizo Plain.
52	85.2	G/F	10.3±2	Both channel segments are incised about 1 m and have similar widths and slope angles.	As above.
		P	28.8±1.5		
53	85.2	G/F	9.5±1.25	Beheaded and source gullies are of similar direction, width, and depth.	As above.
54	85.2	P	9.0±0.8	Very short source gully and 1m-wide beheaded channels 10 to 20 cm deep. Secondary fault to SW. 4.7 m right-lateral bend in youngest channel.	As above.
		F	14.5±1		
55	87.8	Exc	8.6±0.8	Beheaded gullies on steep slope.	NW¼ NW¼ sec. 19 T32S, R22E, about 300 m SE of sec. 19/sec. 24 boundary. Carrizo Plain
		G/F	17.5±1.3		
		F/P	26.6±2.3		
56	87.8	P/F	7.5±1.3	Very broad beheaded gully (?) and short scarp-face source gully.	SE of above.
57	87.8	P/F	13.0±1.0+	Broad swale possibly offset from short scarp-face source gully with pre-1857(?) alluvial deposit at fault.	SE of above.
58	87.9	F/G	10.85±.75	Broad swale possibly offset from source gully. Broad fault zone here. Small alluvial deposit at fault.	SE of above.
59	87.9	F/G	8.85±1.5	Scarp-face gully possibly offset across 4½-m wide zone. Alluvial deposits upstream from fault.	SE of above, about 100 m SE of site 55.
60	90.2	F/G	7.3-9.8	Beheaded gully and short source gully. Secondary faults and ambiguous deformation.	NW¼ NW¼ sec. 29, T32S, R22E. About 250 m SE of sec. 29/sec. 30 boundary. Carrizo Plain.
61	90.2	Exc	9.4±0.6	Beheaded gully and very short scarp-face gully.	SE of above.
62	90.3	P/F	17.4±0.6	Offset gully. Deformation in addition to main fault slip is ambiguous because of gully geometry. This figure is perhaps a minimum value, since possible warp is not measured.	SE of above.
63	90.4	G	9.3±0.9	Offset SE channel wall of large stream. Wall NE of fault trace may have sloughed some material since latest movement.	About 100 m SE of site 60.
64	90.8	G/F	8.8±0.6	Channel separated along fault. Shutter ridge in front of channel may be eroded by post-1857 run-off. This may therefore be a minimum value. Possibility of deflection suggests it is a max. value.	SE¼ NW¼ sec. 29, T32S, R22E. About 750 m SE of sec. 29/sec. 30 boundary.
65	92.8	F	6.7±1.5	Very small gully drains across fault trace at 1.2 m-wide bench. Bench and alluvial deposits at bench result in imprecise offset value.	NW¼ sec. 33, T32S, R22E.
66	92.8	G	7.0±1.3	Small gully drains across 1.2 m-wide fault bench. Upstream segment of gully probably warped in 5 m nearest fault trace. Max. value is therefore probably the most reasonable.	SE¼ NW¼ sec. 33, T32S, R22E.

TABLE 1

OFFSET MEASUREMENTS ALONG THE FAULT

Site	Distance SE from Hwy 46	Rating	Offset	Description	Location
67	94.7	P	--	Large channel (∿ 0.8 km long). Downstream segment may have originated across fault from next channel to SE.	T12N, R26W, about 230 m SE from sec. 35/ sec. 36 boundary.
68	94.7	G	12.9±2.5	200-m-long channel SE of 67. Downstream segment must have originated across fault from this channel. Small alluvial deposit at fault makes offset imprecise.	As above.
69	94.7	G	10.8±1	200-m-long channel SE of 68. Comments same as for 68. Good minimum value.	As above.
70	95.3	G/F	14.7±2	Stream channel with alluvium at fault and beheaded channel. 6±2 m is probably a good estimate of the minimum for latest movement. Other P and P/F offsets to SE ∿40 to 110 m suggest ∿6-7 m latest movement.	Sec. 36, T12N, R26W, about 440 m NW of sec. 1/sec. 36 boundary.
73	104.7	G F	10.7±1.5 6.2±1.5	Large deeply-incised gully and gentle gully to SE. The larger value is max. offset value from gentle gully. Lower value is from deeply incised gully.	SE¼ of sec. 22, T11N, R25W. About 530 m NW of sec. 22/sec. 23 boundary.
76	106.4	G	11.9±1.2	Two beheaded gullies and warped scarp-face gully (2 events at least).	NW¼ SW¼ NE¼ sec. 26, T11N, R25W. About 1000 m NW of sec. 25/sec. 26 boundary.
77	107.7	P	7.4±1.5	Deeply-incised 200-m-long channel. Freshest part of free-face of channel wall.	Behind and to NW of "Hanline" Ranch bldgs. SW¼ SW¼ sec. 25, T11N, R25W. About 380 m NW of sec. 25/sec. 36 boundary.
78	107.8		9 ± ½	200-m-long recently-deeply-incised channel (stream cut across fault after previous offset of ≥ 100 m. Freshest part of gully wall may indicate latest movement.	Behind "Hanline" Ranch bldgs. SW¼ SW¼ sec. 25, T11N, R25W. About 275 m NW of sec. 25/ 36 boundary. Southern end of Carrizo Plain.
80	111.0	F	$5.3^{+2.5}_{-0.8}$	Offset fan and gully cutting SW-facing scarplet.	NE¼ NW¼ NE¼ sec. 6, T10N, R24W. About 600 m NW of sec. 5/sec. 6 boundary.
81	111.1	G	6.1-7.2	Scarp-face gully.	SW¼ NE¼ NE¼ sec. 6 T10N, R24W. About 380 m NW of sec. 5/sec. 6 boundary.
82 83 84	112.2	Exc Exc Exc P	6.2±0.3 6.7±0.5 6.4±0.9 13.1±1.2	Small scarp-face gullies and beheaded alluvial fans (see plane-table map). Values measured from map.	NE¼ SW¼ sec. 5, T10N, R24W. About 640 to 720 m SE of sec. 5/sec. 6 boundary (i.e., County Line), along Soda Lake Road.
85	112.4	G	$5.8^{+0.8}_{-2.1}$	Small scarp-face gully and beheaded small alluvial fan.	As above, but about 850 m SE of sec. 5/ sec. 6 boundary.
86	113.1	G/F	4.6±0.6	Scarp-face gully and beheaded gully.	NE side of sag pond NE of Soda Lake Rd. SE¼ sec. 5 T10N, R24W, about 230 m NW of sec. 5/sec. 8 boundary.
87	113.1	G/F	5.2±0.5	As above.	SE of 86.
88	113.1	Exc	3.9-7.4	As above. Fault about 340 m to SW has very fresh scarplet and may help explain low value. May also be fault hidden in pond.	SE of 87.
89	116.5	G	6.2±1.8	Small gully offset across fault zone about 10 m wide. Large ambiguity in offset value results from different orientations of up- and downstream channel segments.	NW¼ SE¼ NW¼ sec. 15, T10N, R24W. About 880 m SE of sec. 15/sec. 16 boundary. NW of mobile home and buildings.
90	117.5	F	15.8±0.9	Gully and beheaded gully near base of scarp. Possibility of fault at base of scarp casts doubt on reliability of this point.	NW¼ SE¼ SE¼ sec. 15, T10N, R24W. About 300 m NW of sec. 15/sec. 14 boundary.
91	120.3	F	7.9±1.8	Broad gully approaches fault from NE on NE side of road. Is narrower in the fault zone. Offset and possible warp included in measurement.	NE¼ SW¼ SW¼ sec. 24, T10N, R24W. About 425 m SE of sec. 24/sec. 23 boundary.
92	125.8	F/G	5.8±0.5	Deeply-incised gully with natural bridge NE of fault and beheaded gully thought to have originated across fault from aforementioned gully.	At boundary of sec. 32 and sec. 33; at NW head of large drainage; T10N, R23W.
93	125.9	G/F G/F	6.7±0.8 6.9±0.6	Shallow gullies upstream from (NE of) fault and recently-incised gullies downstream from fault.	About 75 m SE of sec. 32/sec. 33 boundary. T10N, R23W.
94	126.0	G	5.5±1.2	Large gully.	About 120 m SE of sec. 32/sec. 33 boundary T10N, R23W.
95	135.9	G/F	2.3-5.2	Offset gully. Probably 3.1-4.3 m.	NW¼ SE¼ SE¼ sec. 8, T9N, R22W. About 350 m WNW of fault/sec. 8/sec. 9 boundary.
96	135.9	P/F	1.5-7.0	Offset gully.	About 70 m E of site 95.
97	136.8	G/F	5.5±1.2	Major fork of Santiago Creek is offset.	SW¼ SE¼ SW¼ sec. 9, T9N, R22W. About 90 m WNW of sec. 9/sec. 16 boundary.
98 99	140.4 "	G	3.9±1.0 3.6±0.5 5.2±0.5	Offset of two small gullies on alluvial flat, about 20 m east of center of dirt road. Although these offsets are on the main trace, the fault zone in this area is characterized by numerous strands, so these are likely to be minimum values for the entire zone.	Boundary of SW¼ and SE¼ of NE¼ SW¼ sec. 14, T9N, R22W. About 55 m N of 6000' contour on Vedder and Wallace, 1970, strip map of San Andreas fault. (USGS Misc. Geol. Inv. Map I-574). Mil Potrero.
100	147.5	P	6 - 7½	(Paced) Freshest offset on E end of large offset drainage.	Boundary of NW¼ and SW¼ of NE¼ sec. 21, T9N, R21W, E of Mil Potrero, W of Cuddy Valley.
101	155.5	P	6.5±1.5	Gully incised up to 2 m across bench on scarp.	E of 2 homes built directly upon fault. E½ sec. 30, 875 m WNW (along fault) from sec. 30/sec. 29 boundary. Cuddy Valley.
102	180.3	G/F (min)	5.8±0.5	Fault cuts alluvial apron. Offset of top of gully channel wall S of Gorman Post Road. Gully originates in largest canyon to N across road.	W of supply yard built upon fault and surrounded by chain-link fence. SE¼ SW¼ SW¼ sec. 15, T8N, R18W.
103	180.3	P/F	5.5±2	Possible offset of the old Gorman Post Rd. (See Wood, 1955, p. 51)	W of site 102 about 10 m.

TABLE 1

OFFSET MEASUREMENTS ALONG THE FAULT

Site	Distance SE from Hwy 46	Rating	Offset	Description	Location
104	180.3	F	6.2±2	Broad, shallow gully on alluvial apron may have incised gully across fault for a couple tens of meters.	E of site 101 and site 102.
105	182.1	Exc (min)	2.4-6.4	100-m-long gully. 3.4-5.2 most likely offset value. Other traces to S appear to be primarily vertical slip. Still, this should be considered a minimum figure for 1857.	First gully cutting scarp SE of aqueduct. Boundary of NE¼ and SE¼ of NW¼ sec. 23, T8N, R18W. Near Quail Lake.
106	189.6	F/P	14.3±1.5	Gentle gully in alluvium may have been formed downstream from now-deeply-incised gully N of road. Another active trace to SW.	Near Rancho Corona del Valle. About 805 m ~NW of corner of secs. 27, 28, 33, and 34, T8N, R17W.
107	190.1	Exc/G (min)	7.2±0.2	Beheaded channel originally part of a drainage crossing fault. Offset on major trace to S probably accompanied this offset.	At the E entrance to Rancho Corona del Valle, at sharp bend in main hwy. About 380 m ~N of secs. 27, 28, 33, and 34, T8N, R17W.
108	190.9	G/Exc	17.0±2.25	Beheaded channel originally a part of the Robinson Canyon drainage.	Across fault from Robinson Canyon, which is in sec. 34, T8N, R17W.
109	225.9	G/Exc	6.7±0.9	Very short gully sharply offset. 4.3 m stretch appears freshest. Other fault strand ~25 m NE may have ~0.6 m rt. slip.	Center of NE¼ of NW¼ of sec. 12, T6N, R14W Leona Valley.
110	225.9	F/P	3.5±0.6	Very short gully. Minimum value, since fault to NE probably moved in 1857.	SE of site 109.
111	225.9	F/P	1.8±0.3	As above.	SE of site 110.
112	226.3	G	5.0±1.1 6.9±0.9	Gentle 1m-deep scarp-face gully. Unusual bench within fault zone. Lower value assumes gully cut across fault bench parallel to gully trend. Higher value assumes gully cut across fault bench perpendicular to fault trend.	NW¼ NE¼ sec. 12, T6N, R14W. About 650 m NW along fault from sec. 7/sec. 12 boundary
113	226.5	F	11.1±0.6	Scarp-face gully and beheaded gully.	SW¼ NE¼ sec. 12, T6N, R14W. About 490 m NW of sec. 7/sec. 12 boundary.
114	226.6	F	7.5±0.6	Scarp-face gully and beheaded gully.	SE¼ NE¼ sec. 12, T6N, R14W. About 350 m NW of sec. 7/sec. 12 boundary.
115	227.8	G/F	10.5±0.8	Large scarp-face gully. Possible minor trace to NE.	E½ NE¼ SW¼ sec. 7, T6N, R13W. About 875 m NW of sec. 7/sec. 8 boundary.
116	227.8	G/F	10.1±0.8	Deeply-incised scarp-face gully. Offset across two faults.	As above, but about 850 m NW of sec. 7/sec. 8 boundary.
117	227.9	G/F	3.7±0.6	1.2-1.8 m-deep gully.	Between garage and driveway. NW¼ SE¼ sec. 7, T6N, R13W. About 730 m NW of sec. 7/sec. 8 boundary.
118	228.3	G	7.8±1.1	1-m-deep gully crosses fault at trough and mound, and beheaded gully. Present drainage is deflected left-laterally. Measured offset may include some deflection.	SE¼ sec. 7, T6N, R13W. About 350 m NW of sec. 7/sec. 8 boundary. Leona Valley, near 90th St. W.
119	229.3	F/P F/P	2.7±1.2 5.9±1.2	Shallow gully crosses fault bench. Separation at bench is 2.7 m. 5.9 m included warp or older offset across bench.	NW¼ NE¼ NW¼ sec. 17, T6N, R13W. About 1140 m NW of sec. 16/sec. 17 boundary (80th St) Leona Valley.
120	230.3	F	3.4±0.6	Small, incised gully.	SE¼ NE¼ sec. 17, T6N, R13W. About 120 m NW of sec. 16/sec. 17 boundary (80th St)
121	230.4	F	2.7±0.5	Small, incised gully.	At boundary of sec. 17/sec. 16, Leona Valley.
122	230.5	F	3.7±0.3	Shallow gully.	About 100 m SE of sec. 17/sec. 16 boundary.
123	232.0	F/P	2.7±0.5	0.6m-wide, gentle gully.	About 240 m NW of sec. 16/sec. 15 boundary.
124	236.1	F/G	2.9±0.5	Two gullies. Separately, geometries give reasonable doubts as to validity of measurements. Taken together, they are F/G. Bouquet Canyon thrust fault merges with San Andreas here and North Branch occurs to N. Geologically very complex.	SW¼, sec. 24, T6N, R13W. About 360 m SE of sec. 23/sec. 24 boundary.
125	240.9	G/F	3.0±0.7	Small gullies. See plane-table map.	SW¼ SE¼ SE¼ sec. 29, T6N, R12W. About 40 m NW of sec. 29/sec. 32 boundary.
126	"	G/F	2.5±0.1		
127	260.2	F/G	5.5±1.5	Small gully and beheaded gully.	NE side of dirt road, NE¼ sec. 25 T5N, R11W About 510 m NW sec. 25/sec. 30 boundary. SE of Palmdale.
128	260.5	F/G	4.3±0.6	Small gully and beheaded gully.	As above, but about 125 m NW of sec. 25/sec. 30 boundary.
129	260.5	G/Exc	4.6±0.3	Small gully and beheaded gully.	About 50 m SE of site 128.
130	262.1	F/P	4.6±1.5	Large incised gully apparently offset. Freshest walls appear offset 4.6 m.	NW¼ SE¼ SE¼ sec. 30, T5N, R10W. About 290 m NW of sec. 29/sec. 30 boundary.
131	262.5	F	4.4±0.3	Offset gully. Poor control on upstream segment.	Boundary of NW¼ and SW¼ SW¼ SW¼ sec. 29 T5N, R10W. About 64 m SE of sec. 29/sec. 30 boundary.
132	262.6	F/P	2.9±0.3	Large offset gully.	As above, but about 140 m SE of sec. 29/sec. 30 boundary.
133	263.3	G/F	4.6±0.6	Large stream channel. Base of channel wall.	NW¼ NW¼ NE¼ sec. 32, T5N, R10W. About 890 m NW of sec. 32/sec. 33 boundary.
134	263.7	F/G	4.3±0.3	~0.3 m-deep gully may be offset from shallow, closed depression on back-facing scarp.	SE¼ NW¼ NE¼ sec. 32, T5N, R10W. About 530 m NW of sec. 32/sec. 33 boundary.
135	264.1	F	4.7±0.5	Gully incised about 2 m offset at fault bench. Freshest face measured.	NE¼ SE¼ NE¼ sec. 32, T5N, R10W. About 95 m NW of sec. 32/sec. 33 boundary.
136	264.2	G/Exc	4.4±0.6	Scarp-face gully has rejoined its beheaded segment downstream from fault bench.	W½ SW¼ NW¼ sec. 33, T5N, R10W. About 20 m SE of sec. 32/sec. 33 boundary. About 450 m NW of 106th St.

TABLE 1

OFFSET MEASUREMENTS ALONG THE FAULT

Site	Distance SE from Hwy 46	Rating	Offset	Description	Location
137	264.4	Exc	11.6±0.5	Large gully and beheaded gully separated along fault bench.	SW¼ SW¼ NW¼ sec. 33, T5N, R10W. About 155 m SE of sec. 32/sec. 33 boundary. About 310 m NW of 106th St.
138	264.4	F/P	3.4±0.6 6.7±0.6 10.7±0.9	Scarp-face gully and beheaded gullies separated along fault bench.	About 40 m SE of site 137.
139	265.6	Exc/G	10.4±1.2	Shallow gully and beheaded gully.	SE¼ SW¼ SW¼ sec. 34, T5N, R10W. About 100 m NW of sec. 34/sec. 3 boundary.
140	265.6	G/F	4.3±1.2	Shallow 5-m-wide gully offset across fault moletrack.	A few meters SE of site 139. W of 131st St.
141 142	271.1 "	G Exc	2.7±0.3 2.7±0.2	Scarp-face gullies drain SW toward mountains. Offset along SW-most of traces in this area. Offset on other traces in 1857 very likely.	NE¼ of SW¼ and NW¼ of SE¼, of NE¼ sec. 12, T4N, R10W. E. of Pallett Creek.
143	277.3	P	$7.6\text{-}9.8\pm^{1.5}_{0.9}$	Channel (∿1.5 m deep at fault and 6 m wide) deflected and/or offset. Other faults sub-parallel may have moved in 1857.	SE¼ SW¼ SW¼ sec. 15, T4N, R9W, about 335 m ESE of sec. 15/sec. 16 boundary. Shoemaker Canyon.
144	279.3	G	4.9-7.3	Shallow, small gully offset along clear fault trace.	Boundary of NW¼ and NE¼ of SE¼ NW¼ sec. 23, T4N, R9W. About 700 m ESE of sec. 22/sec. 23 boundary.
145	279.8	Exc	9.0-11.3	Channel offset sharply.	SE¼ SW¼ NE¼ sec.23 ∿510 m WNW of sec. 23/24 boundary.
146	287.4	F/P	6.4±1.2	Deeply-incised creek appears to be offset. Creek only recently captured the headwaters of Appletree Campground. This explains the small offset value.	Runs through Appletree Campground and is about 1 km SE of Jackson Lake.
147	289.1	Exc/G	3.1±0.3 6.7±0.3	Offset gully and older beheaded gully on steep slope near octagonal building.	About 630 m NW along fault from Big Pine road intersection. SW¼ NE¼ NE¼ sec. 3, T3N, R8W. About 270 m NW of sec. 2/sec. 3 boundary.
148	290.8	Exc P	12.2±1.5 2.0±0.6	Offset(?) gully and beheaded channel on steep slope across from Sawmill Canyon (NW of Holiday Hill Ski Lift) Fault marked by bench. Smaller offset has odd geometry.	NW¼ NE¼ SE¼ sec. 2, T3N, R8W. About 380 m WNW of sec. 2/sec. 1 boundary.
149	291.0	Exc	13.4±0.9	Offset channel N of road between Holiday Hill and Sawmill Canyon.	SE¼ NE¼ SE¼ sec. 2, T3N, R8W. About 160 m WNW of sec. 2/sec. 3 boundary.
150	291.5	F	3.6±0.2	Shallow gully and possibly beheaded gully (0.3 m deep and 1 m wide).	In thick chapparal among willow thickets at about 6560' contour N of road about 270 m SE along fault from Ski Lift. NE¼ SW¼ SW¼ sec. 1, T3N, R8W.
151	296.8	F/G	3.0±1.2	Shallow channel offset at "moletrack" between modern channel of Heath Creek and "moletrack" with tilted trees to SE. Visible on 1930 photos. Now (8 Aug. 1977) buried by flood control levee.	SE¼ NW¼ NW¼ sec. 16, T3N, R7W. About 210 m ESE of sec. 16/sec. 17 boundary. Wrightwood, E side of Heath Canyon.
152	301.0	F F	3.0±0.6 3.0±0.6	Apparent offset of both banks of a wide channel choked with debris-flow deposits.	About 80 m SW of Lone Pine Canyon Road about 270 m from road/channel intersection. NW¼ NE¼ SW¼ sec. 23, T3N, R7W. About 670 m SE of sec. 23/sec. 22 boundary. Lone Pine Canyon.
153	322.8	F/P	4.4±0.9	Possible offset of 1-1.5m-high terrace SE of active channel. Appears to be along fault zone, but heavy brush may conceal other traces.	Cable Canyon, near San Bernardino. T2N, R5W.
154	322.9	Exc	11.3±1.2	Channel (∿1 m deep, 1/2-2/3 m wide) apparently offset along fault trace.	In very heavy brush SE of main active channel of Cable Canyon. T2N, R5W.
155	325.3	Exc	0-1.5	Channel (∿2-2½-m-deep, 7 m wide) runs sub-parallel to fault is not clearly offset along fault. Slight misalighnment of channel wall on SE suggests possibility of a meter or so. Slight misalignment of channel wall on NW suggests about 30 cm offset.	Boundary of NW¼ and NE¼ of SW¼ sec. 36, T2N, R5W, near San Bernardino. Freshly burned over in summer 1975.
156	326.8	F/P	0.9±0.2	Small gully and ridge on NW flank of channel incised ∿1 m is apparently offset along fault trace. Ridge and gully may be post-1857 and/or man-made.	∼ 30m S of sec. 31 boundary, T2N, R4W in sec. 6, T1N. ∼ 180m E of corner secs. 1, 6, 31, 36.
157	327.2	F/P	1.2±0.1	Small gully may be offset.	W of Devil Canyon, E of residences. As above, but about 600m ESE of corner.
158	329.9	P	0.8±0.8	Small gully may be offset.	E of Devil Canyon about 140m S of sec. 5, T1N, R4W.

displacement occurred during one event. If the older fans had been gradually displaced from their sources, intermediate deposits would exist between the older and younger fans. If, for example, the $6\frac{1}{2}$-m displacements had occurred in two distinct $3\frac{1}{4}$-m increments, 100 years apart, a small fan probably would be apparent between each pair of older and younger fans. Or if rather continuous creep had accomplished $3\frac{1}{4}$-m of the $6\frac{1}{2}$-m offset prior to a $3\frac{1}{4}$-m slip event, the older fan apices would be about $3\frac{1}{4}$ m wide along the fault trace.

Clearly the sharpness of the apices and the fan symmetry do not allow one to rule out the possibility of several small aseismic or seismic events, accompanied by slip of up to several tens of centimeters, during deposition of the older or younger fans.

Nor does it disallow the possibility of two several-meter slip events only a few years apart. However, one can conservatively conclude from the fan morphology that at least 90 per cent of the $6\frac{1}{2}$-m offset was accomplished over less than one or two decades. From what is known of the historical seismicity, almost the full $6\frac{1}{2}$-m offset must have been associated with the 1857 earthquake and afterslip.

This site may also contain information on the length of the time interval between the 1857 event and its immediate predecessor. The three older fans contain $2\frac{1}{2}$ to $3\frac{1}{2}$ times more material than their younger companion fans. (Volumes for the middle and northwesternmost old and young fans crudely calculated from the contours are, from northwest to southeast, 7.3 m^3, 2.1 m^3, 11.4 m^3, and 4.6 m^3). If rates of accumulation have been nearly constant over the past several hundred years, this would mean that the older fans received sediment from the gullies during a span of time about $2\frac{1}{2}$ to $3\frac{1}{2}$ times longer than the younger fans. A rough estimate of the time between the 1857 event and its predecessor would be (120 years) $\times$ ($2\frac{1}{2}$ to $3\frac{1}{2}$) or about 300 to 420 years. This suggests that a large 1470 $\pm$ 40 A.D. event identified about 160 km along the fault to the southeast (Sieh, 1978) may also have been associated with large offset here. Admittedly, the validity of this inference depends greatly upon whether the fans accumulated gradually over a span of many years or rapidly, as the result of only a few intense storms.

Site 31. Site 31 is located about 3 km from the southeastern terminus of a remarkably rectilinear 16-km-long fault trace in the northern Carrizo Plain (Figure 5). Offsets along this trace cluster around 9- to $9\frac{1}{2}$-m values. From the vicinity of site 31 to its southeastern terminus, the trace traverses a gently sloping young alluvial fan surface. Although historical deposits have completely buried all evidence of the 1857 rupture over much of this surface, small graben and horsts, *en echelon* fractures, scarps and other microtopographic disturbances from the latest event remain well expressed for a kilometer or more southeast of site 31.

At site 31 a small gully, incised about 40 cm into the young alluvial surface, is offset about 9 m (Figure 10). Accurate measurement of the offset is difficult because sediment deposited since the offset occurred obscures the location of the offset reference points. Upstream from the fault, deposition of alluvium has broadened the floor of the channel (compare section B-B′ and C-C′, Figure 10). Thus it appears that the northwest edge of the channel-fill is offset only about 6 m and the southeast edge of the channel-fill is offset more than 12 m. A true offset (about 9 m) is obtained by measuring the offset of the center of the stream channel or the offset of the top of the southeastern bank.

Sites 11, 12, and 13. Several sites in Bitterwater Valley, between Cholame and the Carrizo Plain, display offsets of between 3 and 4 m (Figure 5). At site 12 a deeply incised gully is probably offset about 3.2 m (Figure 11). An older beheaded segment is offset about 20 m. In the next gully to the southeast (site 13), the northwestern edge of a landslide scar is offset about 3.4 m (Figure 7). Deflections in the gully channel and walls and in the landslide scar are about the only geomorphic evidences of the fault trace between sites 12 and 13. Slope-wash processes have completely buried or eroded evidence of the surface trace elsewhere in the area.

The history of the gully at site 12 is interpreted as follows

1. Prior to the events that produced the latest approximately 20 m of offset, a steep ($\sim$18°), shallow gully coursed down the hillside and across the fault.
2. Following initial offset of the gully, gully activity was too slight to establish a new channel segment downstream from the fault.

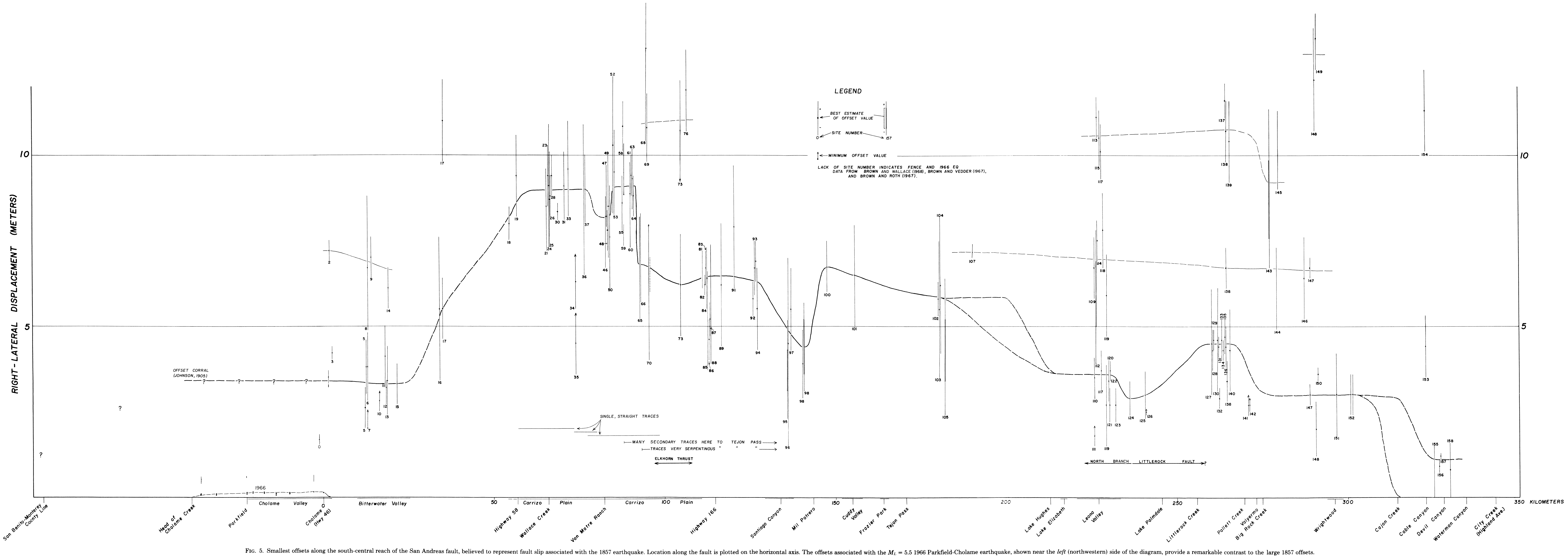

FIG. 5. Smallest offsets along the south-central reach of the San Andreas fault, believed to represent fault slip associated with the 1857 earthquake. Location along the fault is plotted on the horizontal axis. The offsets associated with the $M_L = 5.5$ 1966 Parkfield-Cholame earthquake, shown near the *left* (northwestern) side of the diagram, provide a remarkable contrast to the large 1857 offsets.

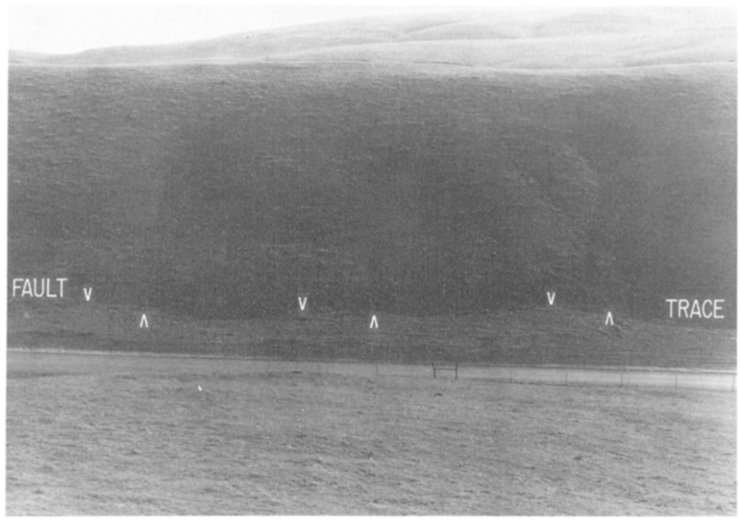

FIG. 6. Small alluvial fans (V) offset about $6\frac{1}{2}$ m from their source gullies (Λ) illustrate the subtle nature of some of the features that were offset in 1857. View is northeastward. Sites 82, 83, and 84 about 2.9 km northwest of Highway 166 on the Soda Lake Road near the southeastern end of the Carrizo Plain.

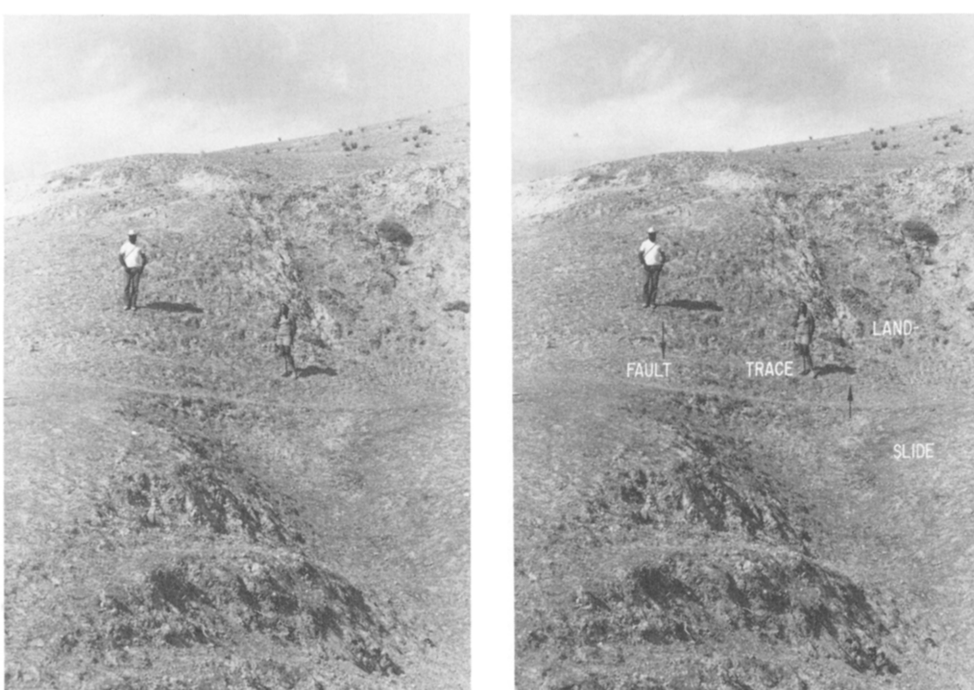

FIG. 7. The two photographs provide a stereoscopic view of the offset edge of a landslide scar (site 13). Amount of offset (about 3.4 m) is indicated by positions of the two individuals. View is northeastward.

3. Just prior to the 1857 event, the currently active channel segment downstream from the fault was created.
4. This gully was offset about 3.2 m in 1857.

5. The majority of the gully incision is probably historical, judging from the freshness of the gully walls.

Of primary interest at site 11 is one of two small gullies (Figure 12) which are cut into a small alluvial terrace and drain into a large channel which is offset about 70 m. Only a small segment of the larger offset channel appears (in the *lower right corner*) on Figure 12. The southeastern of the two gullies may be offset about 4 m. Small scarps crossing the gully at the fault may be remnants of the 1857 disturbance. If so, their presence would indicate very little gully activity since the 1857 rupture.

Site 1. Southeast of Highway 46 1.3 km, just southwest of the county road paralleling the fault, a small channel appears to be offset about 3.5 m (Figure 13). In this vicinity, the fault trace extends along a bench/trough a few meters up the side of a hill. That the channel at one time coursed southeastward along the bench/trough is indicated by an old beheaded gully about 45 m to the southeast (not shown on the figure). This older beheaded drainage has not been in operation for a long time, however, because the bench/trough gradient is now strongly in a direction

FIG. 8. Abandoned gully (↓) offset about 7.8 m from gully (↑) cut into fault scarp (site 48). A new gully segment downstream from the gully that cuts into the fault scarp was created some time after 1857. Stereoscopic view is northeastward.

opposite to that required. The currently active gully is deeply incised into the bench. This gully is relatively young, because the slopes of its walls are steep (~23°) and uniform, and because the offset is small. By restoring the contours to their probable position before incision of this segment (Figure 14), one can see that the gully may have formed at the lowest point in the rim of the trough. This suggests the following developmental history

1. At some time in the late Holocene, waters flowed down the upstream segment, diverting southeast along the bench/trough and emptying out of the trough through the gully now 45 m to the southeast.
2. Repeated fault slip eventually reversed the gradient of the segment along the bench/trough, isolating (beheading) the downstream gully segment.
3. For some time the waters had no channelized outlet across the fault. Thus, they were ponded in the bench/trough, perhaps washing over its lip at "A" (Figure 14) when the holding capacity of the trough was exceeded, or perhaps simply soaking into the materials of the fault zone. In any case, a new gully segment was not incised in the process of draining the trough.
4. Eventually, perhaps only 150 years ago, one flood discharge filled the trough and excess water began to spill out of the trough, over the rim at its lowest

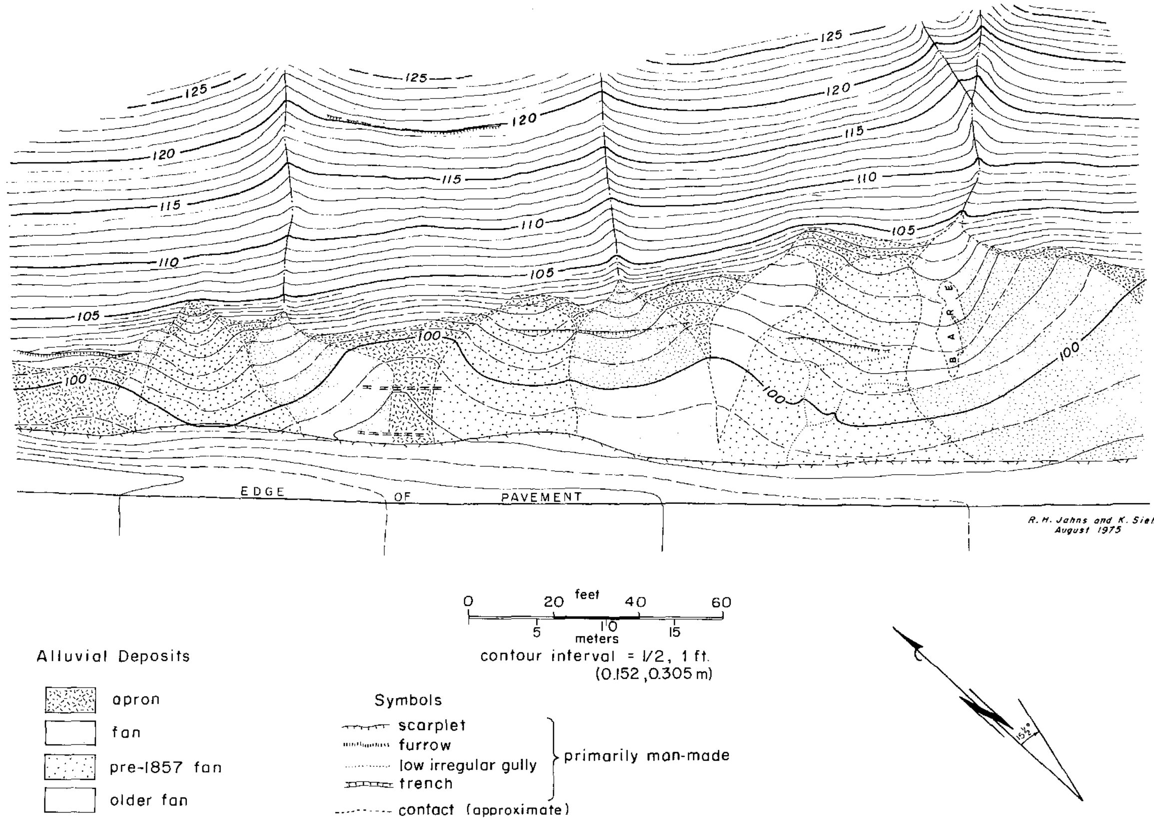

FIG. 9. Map of small alluvial fans (sites 82, 83, and 84) shown in Figure 6. Three older fans are offset about $6\frac{1}{2}$ m from their source gullies. Three younger fans are not offset from the gullies. Most, if not all, of the $6\frac{1}{2}$-m offset probably occurred in 1857.

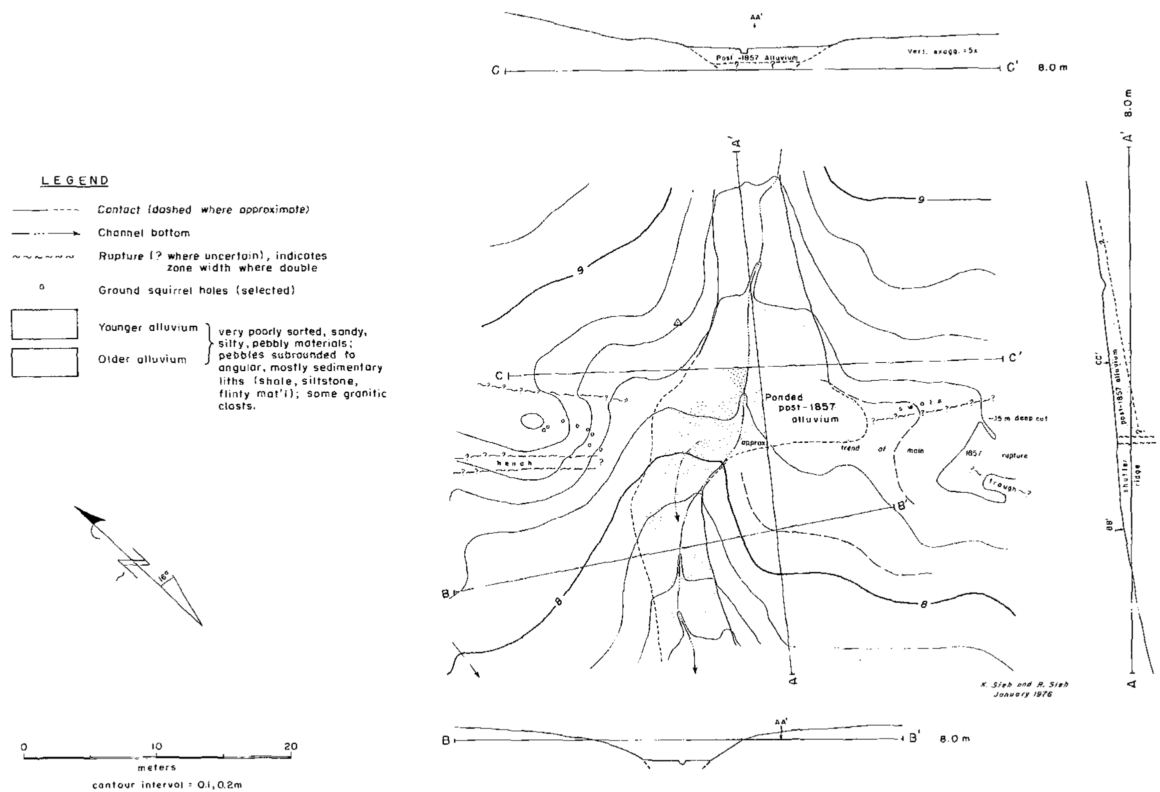

FIG. 10. Small channel offset about 9 m on the San Andreas fault, Carrizo Plain (site 31). Alluvium deposited in the channel upstream from the fault complicates measurement of the offset, all of which probably is associated with the 1857 earthquake.

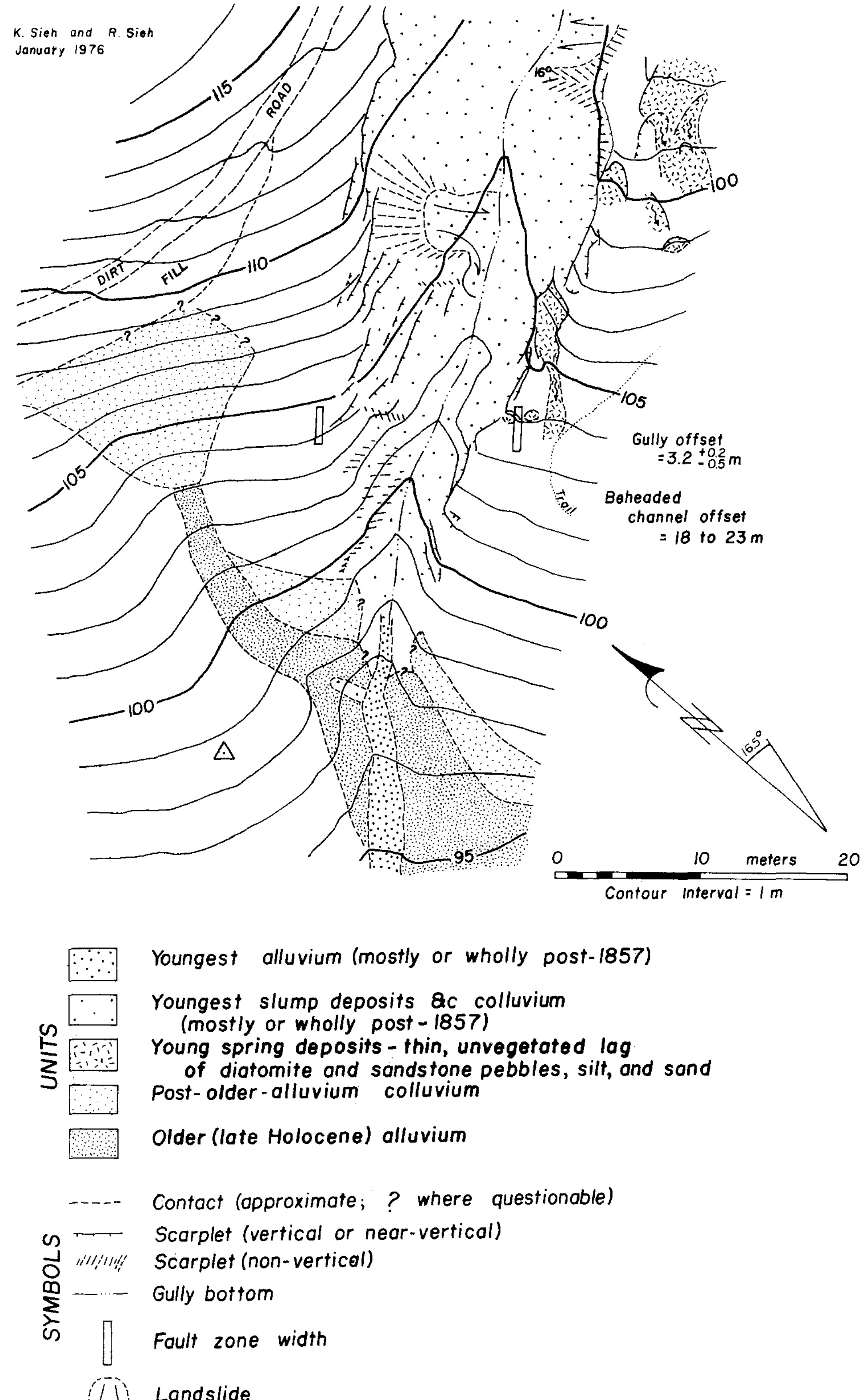

FIG. 11. Gully offset about 3.2 m along the San Andreas fault, Bitterwater Valley (site 12). Erosion within the gully since the 1857 earthquake has removed any obvious evidence of the offset, but a subtle right-lateral separation of the channel segments upstream and downstream from the fault zone remains. A beheaded channel (dense stipple pattern) is offset about 20 m from the upstream segment of the modern gully. Several meters of incision of the modern gully have occurred since the beheaded gully was offset.

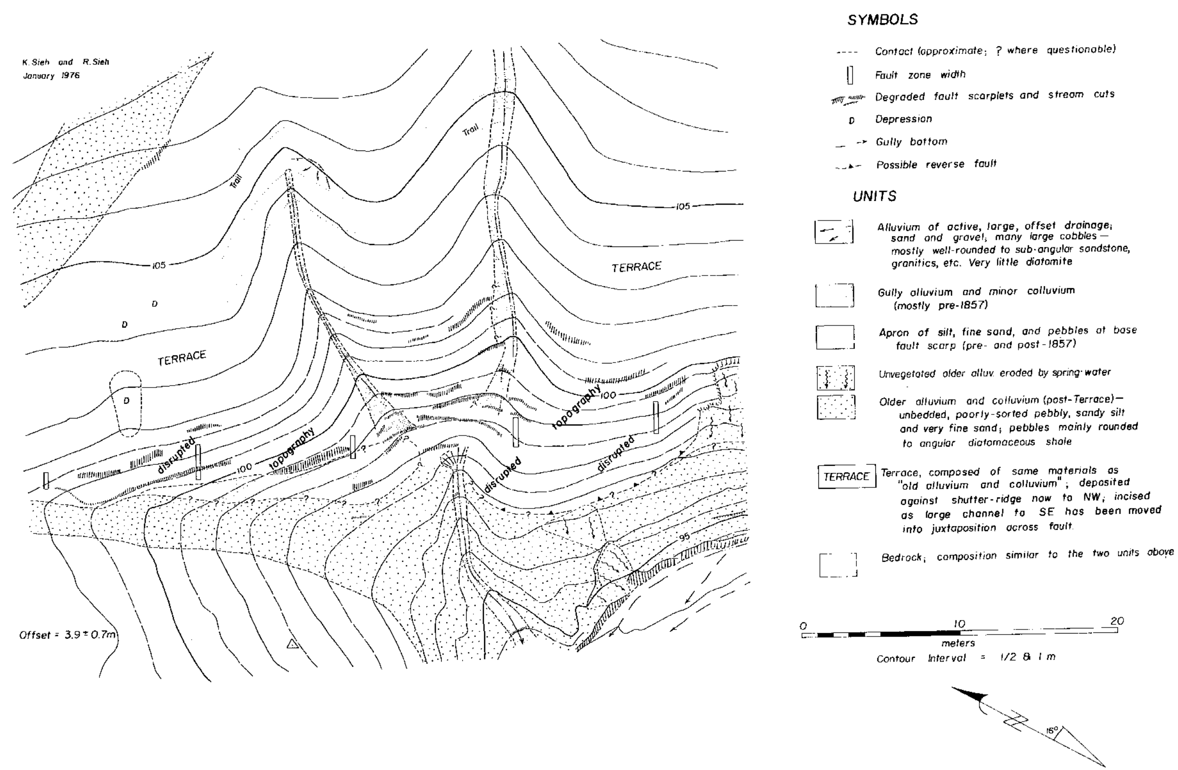

FIG. 12. Gully offset about 3.9 m along the San Andreas fault, Bitterwater Valley (site 11). The recent trace of the fault traverses the base of an alluvial terrace, which is cut by two small gullies. A small segment of a large channel which is offset about 70 m appears in the *lower right* corner. The more southeasterly of the two small gullies cutting the terrace probably was offset about 3.9 m from its downstream segment in 1857.

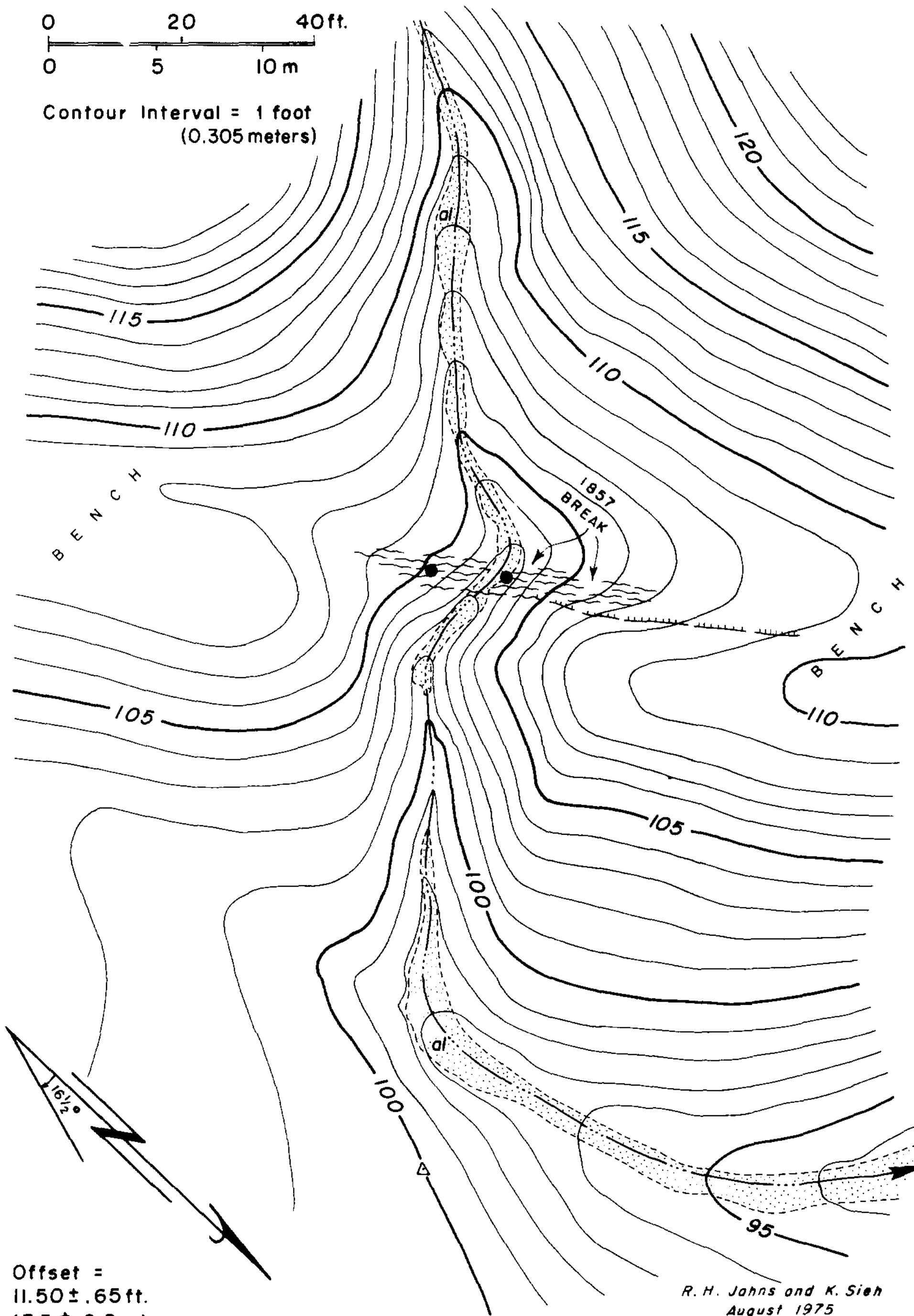

FIG. 13. Gully offset about 3.5 m along the San Andreas fault at the south end of Cholame Valley (site 1). Although a small amount of fault slip has occurred here in recent years in association with one or more moderate earthquakes, most of the offset (indicated by the large dots) probably occurred in 1857.

point "A" (Figure 14). Headward erosion eventually breached the trough, creating the currently active gully segment.

5. Postincision slip events have offset this new segment about 3.5 m.

This site 1 channel was offset about 3 cm during the 1966 Parkfield-Cholame earthquake and afterslip sequence. [From Brown and Vedder, 1967, Figure 2 and Table 2: F-28 was offset $\frac{1}{2}''$ on 1 July 1966 and is 1.6 km SE of Highway 46. F-27 was offset 1 to 1.4″ on 1 July 1966 and is 1.05 km SE of Highway 46. Site 1 is 1.3 km SE of Highway 46, about equidistant from F-27 and F-28. Therefore, let us assume the

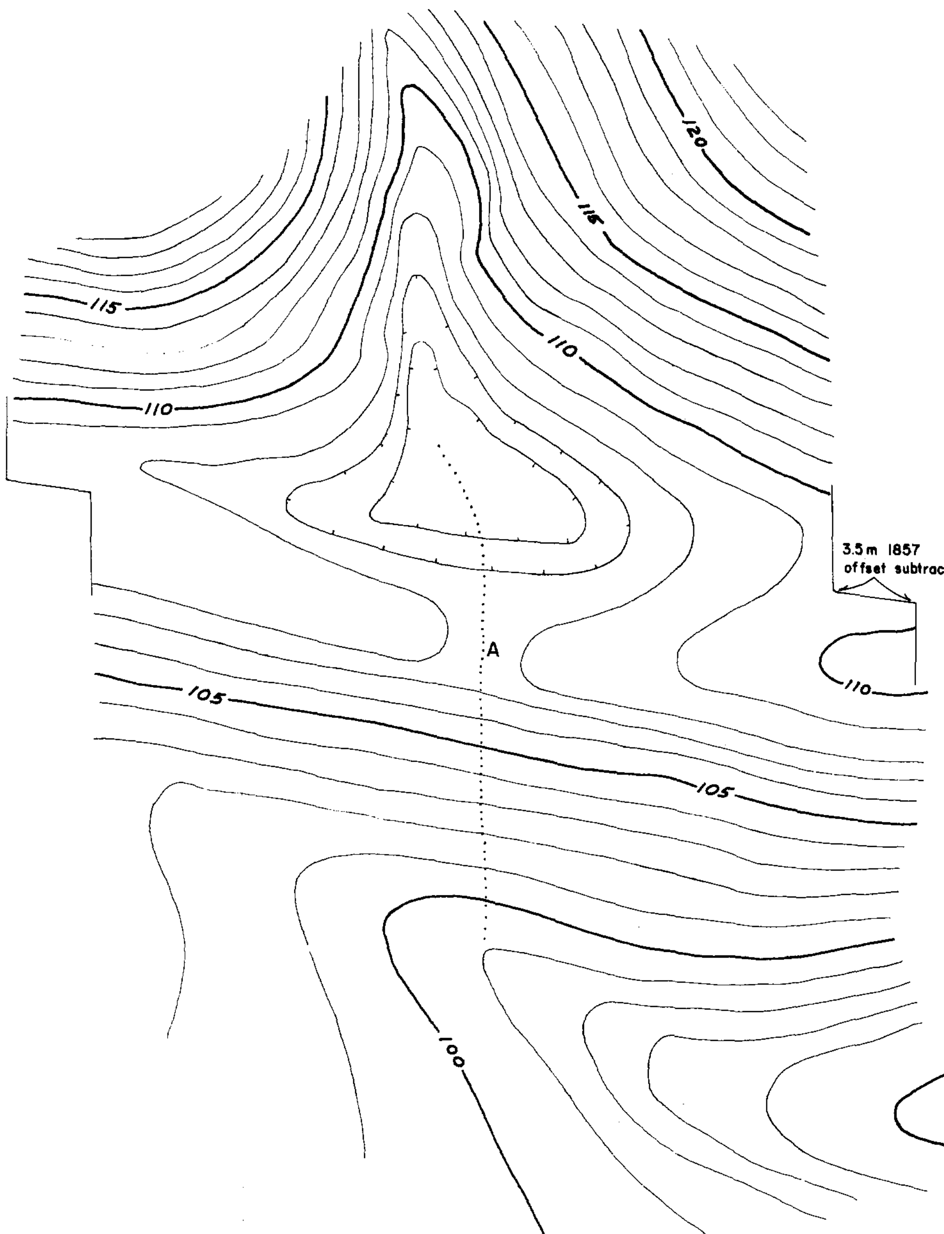

FIG. 14. Hypothetical configuration of site 1 prior to offset in 1857 and prior to gully incision.

site 1 offset on 1 July 1966 was the average of F-28 and F-27, or 0.75 to 0.95″ (1.9 to 2.4 cm). At Highway 46 the 1 July 1966 offset (3.3″) became 4.6″ by the time aftercreep had ceased (Wallace and Roth, 1967, Figure 25). Let us assume the offset at site 1 grew by the same percentage. Site 1 1966 offset is, thus, (1.9 to 2.4 cm) ×

(4.6/3.3) = 2.6 to 3.3 cm.] Episodes similar to the 1966 sequence occurred in 1934, 1922, and 1901. Each of these is associated with surface ruptures in the Parkfield-Cholame area. It seems reasonable to assume that these three sequences were also associated with similar accounts of slip at site 1. Thus, the 1857 slip at this point might be 3.5 m − 4 (3 cm) = 3.4 m. There is no way of judging at this time if moderate pre-1857 events also contributed to the offset of this channel, so one can

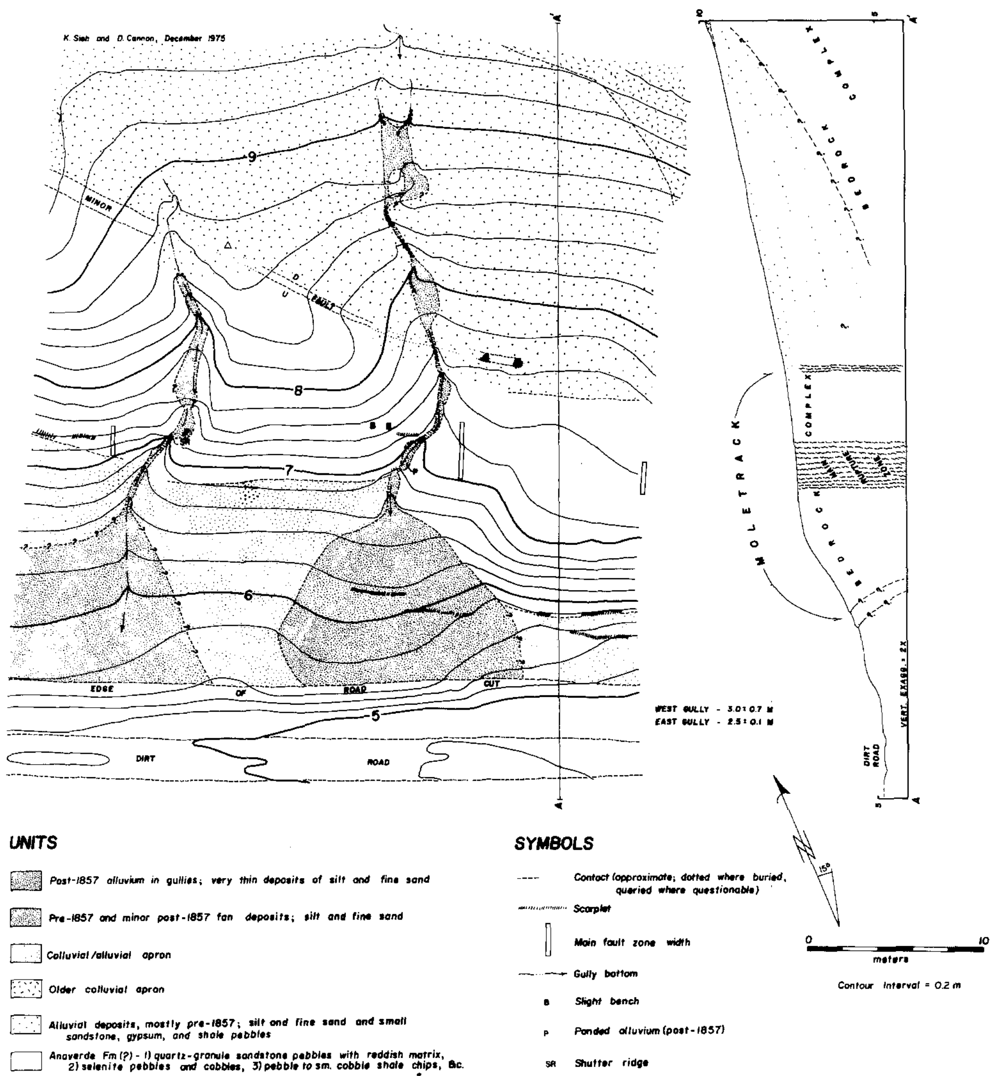

FIG. 15. Gullies offset about 2.5 and 3.0 m along the San Andreas fault near Palmdale (sites 125 and 126).

only consider site 1 to provide a maximum 1857 slip value.

Offsets 125 and 126. West of Palmdale, slip on the San Andreas fault, presumably in 1857, offset two small gullies about $2\frac{1}{2}$ and 3 m (Figure 15). Prior to offset, the gullies had been cut into the bedrock complex which crops out on either side of the fault trace. Small discontinuous and subdued scarps still remain at the boundaries of the bedrock complex and in the main fault zone, 120 years after their creation. Most 1857 microtopography, however, has been masked. The presence of two small scarps on the fan deposits at about the 6-m contour suggests that very little deposition has occurred since 1857 at this site. Judging from the fan contours, slip on the secondary faults which produced these scarps may have included as much as 1 m of strike slip. Thus the $2\frac{1}{2}$-m gully offset within the principal fault zone must be viewed as a minimum value for the 1857 fault slip.

Secondary faulting. Aside from small secondary faults within the main 1857 rupture zone, some faults within a kilometer or two of the San Andreas fault

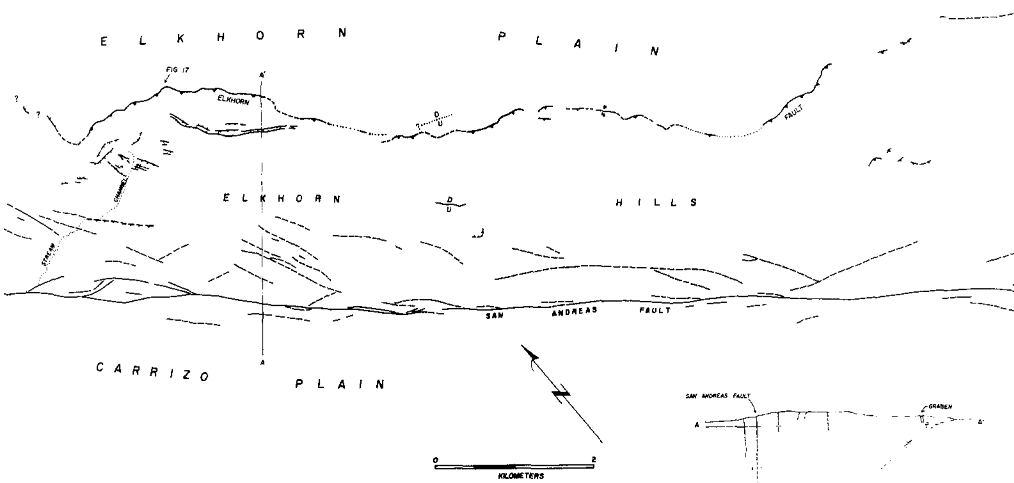

FIG. 16. The Elkhorn and San Andreas faults, southern Carrizo Plain. San Andreas traces are from Vedder and Wallace (1970); Elkhorn traces are from interpretation of aerial photography. Traces are dashed where approximate, dotted where concealed.

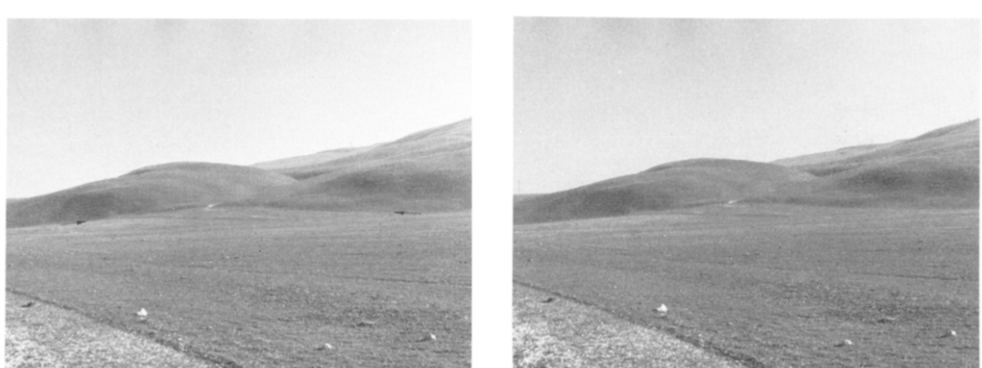

FIG. 17. Small (~1 m) scarp partly in young alluvium at the base of the Elkhorn Hills may have formed in 1857. Stereoscopic view is toward the south from the main road that traverses the Elkhorn Plain. See Figure 16 for location.

probably slipped in 1857. Most of these faults are less than a kilometer long and show little or no evidence of lateral slip and evidence for no more than a few centimeters of dip slip in 1857. Therefore, their contribution to 1857 fault slip probably is negligible for present purposes of analysis.

Along two reaches of the San Andreas fault, however, secondary faulting and deformation probably amount to a significant percentage of the strike slip on the main trace. From about Littlerock Creek through Leona Valley (see Figure 5), the geomorphic expressions of the Nadeau, Littlerock, and North Branch San Andreas faults, parallel to the San Andreas fault, are generally fresh enough to warrant suspicion that they slipped in 1857 (based on aerial photograph reconnaissance and on personal communication with D. Beebe and J. Kahle, California Division of Mines and Geology, 1976). The lack of small gully offsets along these traces suggests that 1857 offsets are no more than about 1 m. One meter of slip on these faults would almost eliminate the embayment in the slip curve along this 30+-km reach.

Near the southern end of the Carrizo Plain, the San Andreas fault is the southwestern boundary of the 15-km-long Elkhorn Hills (Figure 16). Most of the northeastern base of the Elkhorn Hills displays scarps indicative of thrust faulting. Thus, the Elkhorn Hills appear to constitute a crustal block that has risen between the San Andreas and the thrust fault, herein named the Elkhorn fault. Large linear grabens and closed depressions within the Elkhorn Hills indicate that a great deal

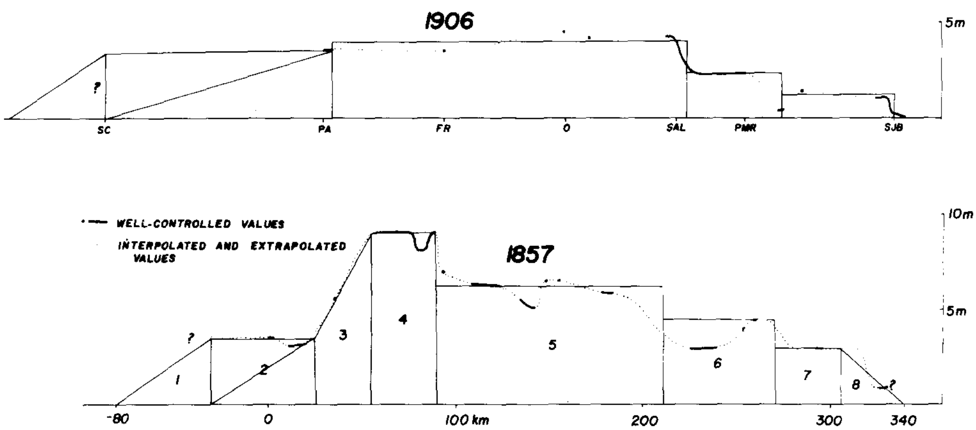

FIG. 18. Simplified slip functions for the 1857 and 1906 earthquakes. Displacements of 1906 simplified and corrected from Lawson and others (1908), Jordan and others (1907), and unpublished field notes of J. C. Branner and students, Stanford University Archives. The numbered rectangles correspond to those segments in Table 3 used to calculate the seismic moment of the 1857 earthquake. Along the 1906 rupture, SC = Shelter Cove, PA = Pt. Arena, FR = Ft. Ross, O = Olema, SF = San Francisco, SAL = San Andreas Lake, PMR = Page Mill Road, and SJB = San Juan Bautista.

of internal deformation has taken place also.

Small scarps in Holocene (?) alluvial deposits along the Elkhorn fault are so fresh as to suggest they may have formed during the 1857 event (Figure 17). Alluviation since that event has obscured any clear indication of a lateral-slip component on this fault. However, it seems very unlikely that the latest event on the sinuous, very low-angle thrust could have included more than 1 m of lateral slip.

Many of the faults within the Elkhorn Hills also display relatively young scarps and, in several closed depressions, many fissures and sinkholes related to "piping" are demonstrably historic.

The evidence for ongoing deformation of the Elkhorn Hills suggests that substantial lateral deformation within the hills may have accompanied the 1857 event. Thus, the change from 9 to 7 m of lateral slip along the San Andreas fault in this region (see Figure 5) may be less abrupt when measured across the entire zone of deformation.

Discussion and Conclusions

Taken together, the youngest offsets along the south-central reach of the San Andreas fault indicate that 1857 fault slip ranges from 3 to $9\frac{1}{2}$ m along the central

300 km of the rupture length (Figure 5). Historical records indicate that the total length of rupture may be as great as about 400 km—from near San Bernardino to the San Benito/Monterey County line.

The mild intensity of the 1857 earthquake at San Bernardino gives ample reason to doubt that the coseismic rupture extended farther southeast than Cajon Pass. The four offsets of approximately 1 m documented near San Bernardino (Figure 5) may have been produced by 1857 afterslip. There is a slim possibility that they originated during the moderate 1907 earthquake. Alternatively, the offsets may be related to activity prior to 1857. The most reasonable estimate of the coseismic length of rupture appears to be about 360 km—from Cajon Pass, northwest of San Bernardino, to the head of Cholame Creek.

TABLE 2

SIMPLIFIED DISPLACEMENTS FOR THE 1857 EARTHQUAKE

i	Segment	Length, L (km)	Displacement, u
1	San Benito Co. line to Cholame Creek	50	150 cm/0
2	Cholame Creek to Km-25	55	340/170
3	Km-25 to Km-55	30	620
4	Km-55 to Km-90	35	900
5	Km-90 to Km-210	120	620
6	Km-210 to Km-270	60	450
7	Km-270 to Km-305	35	300
8	Km-305 to Km-340	35	150

TABLE 3

COMPARISON OF THE 1906 AND 1857 EARTHQUAKE DISPLACEMENT PARAMETERS

	1906	1857
Length of rupture	420 to 470 km	360 to 400+ km
Average displacement	2.8 to 3.2 m	4.5 to 4.8 m
Depth of rupture	10 km	10 to 15 km

The line drawn through the smallest local offset values in Figure 5 indicates the most reasonable fault slip function for the 1857 event. Where data are lacking or ambiguous, a double line indicates favored possibilities.

Several measurements fall below the envelope of 1857 slip values. Among these, features at sites 34, 35, 111, 141, and 142 are offset on only one of two or more overlapping fault strands. Sites 86 and 87 may also display offsets less than the total local 1857 offset for this reason.

Size of the 1857 earthquake. The 1857 slip curve appears to be composed of at least four distinct, relatively flat segments joined by short segments with steep gradients (Figure 18). Separating the 1857 rupture into these segments of length L_i and displacement u_i (Table 2), a seismic moment, m_o, for the earthquake can be calculated

$$m_0 = \mu Z \sum_{i=1}^{8} L_i u_i.$$

This moment includes any afterslip. The depth of rupture, Z, is assumed to be 10 km, fault slip is considered to be uniform with depth and the shear modulus, μ, is 3×10^{11} dynes/cm^2. The seismic moment thus calculated is 5.8×10^{27} dyne-cm. A more conservative estimate, 5.3×10^{27} dyne-cm, excludes segment 1 and assumes that the rupture ended near the head of Cholame Creek.

A recent study of microearthquake activity along the 1857 reach of the fault suggests that "the activity extends down to 15 km or so" (H. Kanamori, written communication, 1977). Thus, 15 km may be a better estimate of the depth of coseismic faulting in 1857 than 10 km. Substituting 15 km for 10 km as the depth of rupture gives $8.8 \geqq m_0 \geqq 8.0 \times 10^{27}$ dyne-cm. Considering the uncertainties in depth of rupture, length of rupture, and slip values at depth, the seismic moment cannot be more precisely defined than $8.7 \geqq m_0 \geqq 5.3 \times 10^{27}$ dyne-cm. This compares with $4.3 \geqq m_0 \geqq 3.5 \times 10^{27}$ dyne-cm, similarly calculated for the great California earthquake of 1906, using a 10-km depth of rupture. Geodetically measured deformation seems to preclude a rupture depth greater than 10 km for the 1906 earthquake (Thatcher, personal communication, 1977).

A comparison of 1906 and 1857 rupture dimensions and amount of slip (Table 3) suggests that the magnitude, M_S, of the 1857 event may have been slightly larger than that of the 1906 event ($M = 8\frac{1}{4}$, Gutenberg and Richter, 1954).

Possible implications of the irregular nature of fault slip associated with the 1857 earthquake. The irregular nature of fault slip associated with the 1857 earthquake raises intriguing questions about long-term slip patterns. If slip rates over a several hundred- or thousand-year period are approximately equal throughout the length of the fault system, those segments which slipped only 3 to 4 m in 1857 must be characterized, between 1857-type events, by activity enabling them to "catch up" to the 6- to $9\frac{1}{2}$-m slip levels experienced along the central portions of the 1857 rupture. That is, slip events of several meters might occur two to three times more frequently along those segments which experienced two to three times less slip in 1857. This hypothesis is supported by an apparent difference in average late Holocene recurrence intervals along the fault. At Pallett Creek, near Valyermo, where 1857 displacement is about $4\frac{1}{2}$ m, the average interval has been about 160 years for the past 1400 years (Sieh, 1978). At Wallace Creek, in the Carrizo Plain, where 1857 displacement is about $9\frac{1}{2}$ m, the average interval for the past 3,400 years has been about 255 years or less (Sieh, 1977, Ch. 2).

An alternative hypothesis is that associated geological structures might enable long-term slip to differ between two segments of the fault. Slip along the White Wolf-Pleito thrust system, for example, might allow long-term differences in slip between the segments of the San Andreas northwest and southeast of Tejon Pass.

Comparison of long-term slip rates determined at a number of widely spaced localities along the fault and dating of specific events at these localities would help answer these questions. The determination of long-term slip rates and specific dates of ancient large earthquakes is thus the subject of ongoing studies.

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References

Agnew, D. C. and K. E. Sieh (1978). A documentary study of the felt effects of the great California earthquake of 1857 (in press).

Allen, C. R. (1968). The tectonic environments of seismically active and inactive areas along the San Andreas fault system, in *Proc. of Conf. on Geologic Problems of the San Andreas Fault System,* W. R. Dickinson and A. Grantz, Editors, *Stanford Univ. Publ., Geol. Sci., Univ. Ser. 11,* 70–82.

Branner, J. C. (1917). The Tejon Pass earthquake of October 22, 1916, *Bull. Seism. Soc. Am.* **7,** 51–59.

Brown, R. D. and J. G. Vedder (1967). Surface tectonic fractures along the San Andreas fault, in *The Parkfield-Cholame California, Earthquakes of June-August 1966, U.S. Geol. Surv. Profess. Paper 579,* 2–23.

Brown, R. D. and R. E. Wallace (1968). Current and historic fault movement along the San Andreas fault between Paicines and Camp Dix, California in *Proc. of Conf. on Geologic Problems of the San Andreas Fault System,* W. R. Dickinson and A. Grantz, Editors, *Stanford Univ. Publ., Geol. Sci., Univ. Ser. 11,* 22–41.

Brune, J. and C. R. Allen (1967). A micro-earthquake survey of the San Andreas fault system in southern California, *Bull. Seism. Soc. Am.* **57,** 277–296.

Gutenberg, B. and C. F. Richter (1954). *Seismicity of the Earth and Associated Phenomena,* Ed. 2, Princeton University Press.

Hileman, J. A., C. R. Allen, and J. M. Nordquist (1973). *Seismicity of the Southern California Region, 1 January 1932 to December 1972,* California Institute of Technology, Seismol. Laboratory, Contribution 2385.

Johnson, H. R. (1905). Unpublished Field Notebook #3354, U.S. Geological Survey Archives, Denver, Colorado.

Jordan, D. S. and others (1907). *The California Earthquake of 1906,* Robertson, San Francisco, 371 pp.

La Marche, V. C. and R. E. Wallace (1972). Evaluation of effects on trees of past movements on the San Andreas fault, northern California, *Bull. Geol. Soc. Am.* **83,** 2665–2676.

Laughlin, H., R. Arnold, and W. Kew (1923). Southern California earthquake of July 22, 1923, *Bull. Seism. Soc. Am.* **13,** 105–106.

Lawson, A. C. and others (1908). *The California Earthquake of April 18, 1906, Report of the State Earthquake Investigation Commission,* Carnegie Inst. of Washington, Washington, D.C., 2 vols. and Atlas, 461 pp.

Noble, L. F. (1954). Geology of the Valyermo quadrangle and vicinity California, *U.S. Geol. Survey,* GQ50.

Page, R. (1970). Dating episodes of faulting from tree rings: effects of the 1958 rupture of the Fairweather fault on tree growth, *Bull. Geol. Soc. Am.* **81,** 3085–3094.

Schuyler, J. D. (1896 to 1897). Reservoirs for irrigation, *U.S. Geol. Survey, 18th Annual Rpt., pt. 4,* 617–740.

Sieh, K. E. (1977). A study of late Holocene displacement history along the south-central reach of the San Andreas fault, *Ph.D. Dissertation,* Stanford Univ., Stanford, California.

Sieh, K. E. (1978). Pre-historic large earthquakes produced by slip on the San Andreas fault at Pallett Creek, California, *J. Geophys. Res.* **83,** 3907–3939.

Vedder, J. G. and R. E. Wallace (1970). Map showing recently active breaks along the San Andreas and related faults between Cholame Valley and Tejon Pass, California, *U.S. Geol. Survey Misc. Geol. Inv.* Map I-574.

Wallace, R. E. (1968). Notes on stream channels offset by the San Andreas fault, southern Coast Ranges, California, in *Prof. of Conf. on Geologic Problems of the San Andreas Fault System,* W. R. Dickinson and A. Grantz, Editors, *Stanford Univ. Publ., Geol. Sci., Univ. Ser. 11,* 6–21.

Wallace, R. E. and E. F. Roth (1967). Rates and patterns of progressive deformation, in *The Parkfield-Cholame California, Earthquakes of June-August 1966, U.G. Geol. Survey Profess. Paper 579,* 23–40.

Wood, H. O. (1955). The 1857 earthquake in California, *Bull. Seism. Soc. Am.* **45,** 47–67.

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